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(12) **United States Patent**  
**Cao et al.**

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(45) **Date of Patent:** **\*Sep. 24, 2024**

(54) **CUTTING ELEMENTS, AND RELATED EARTH-BORING TOOLS, SUPPORTING SUBSTRATES, AND METHODS**

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patent is extended or adjusted under 35  
U.S.C. 154(b) by 0 days.

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claimer.

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(51) **Int. Cl.**

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**B24D 18/00** (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ..... **E21B 10/5735** (2013.01); **B24D 18/0009**

(2013.01); **C04B 35/528** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC ..... E21B 10/46; E21B 10/54; E21B 10/5735;

E21B 10/5673; C04B 35/528;

(Continued)

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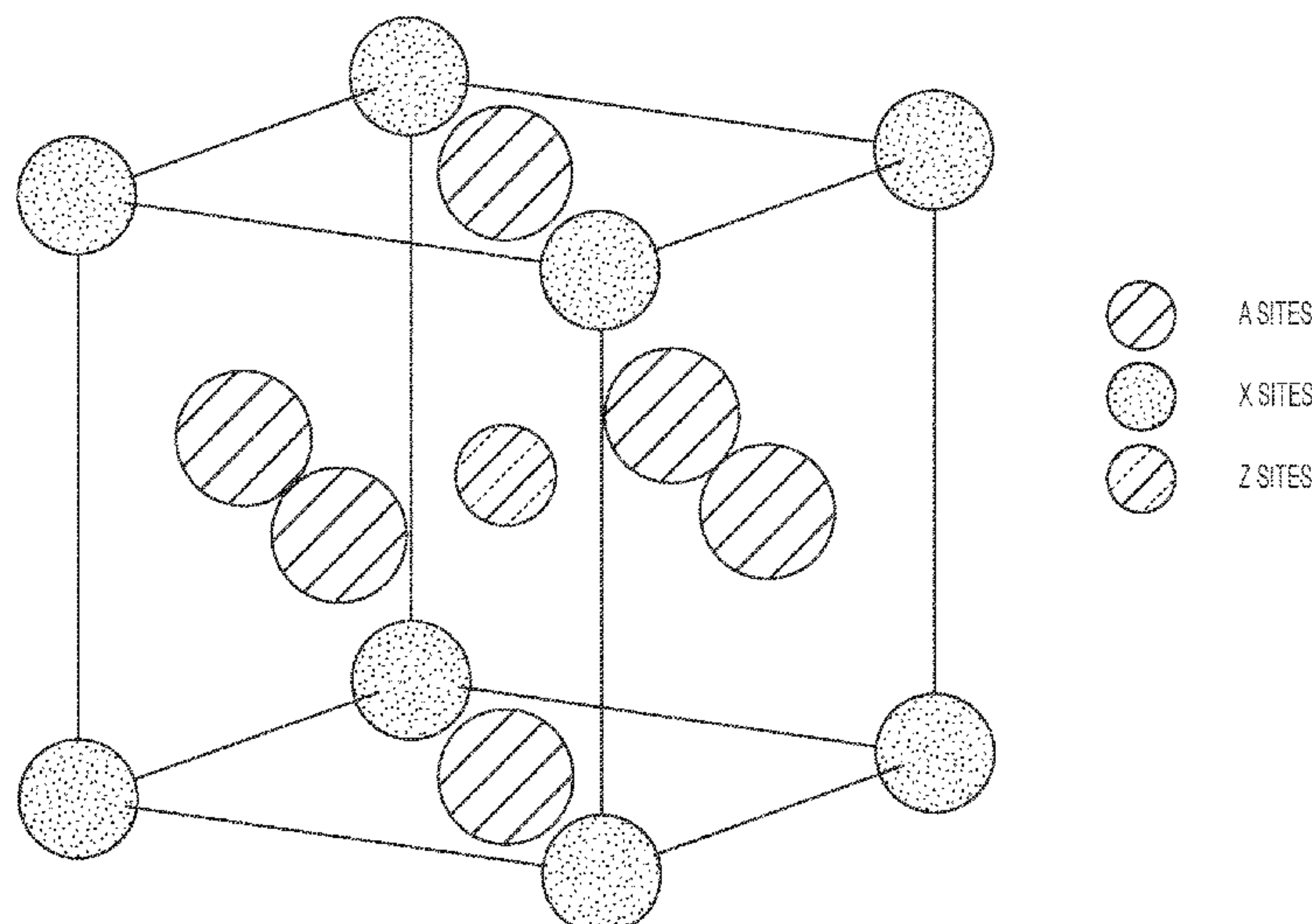
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(57) **ABSTRACT**

A cutting element comprises a supporting substrate, and a  
cutting table attached to an end of the supporting substrate.  
The cutting table comprises inter-bonded diamond particles,  
and a thermally stable material within interstitial spaces  
between the inter-bonded diamond particles. The thermally  
stable material comprises a carbide precipitate having the  
general chemical formula,  $A_3XZ_{n-1}$ , where A comprises one  
or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb,  
Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au,  
Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm,  
Yb, Lu, Ac, Th, Pa, and U; X comprises one or more of Al,  
Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P; Z comprises  
C; and n is greater than or equal to 0 and less than or equal  
to 0.75. A method of forming a cutting element, an earth-  
boring tool, a supporting substrate, and a method of forming  
a supporting substrate are also described.

**20 Claims, 8 Drawing Sheets**





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(58)	<b>Field of Classification Search</b>		9,272,392 B2	3/2016	Mukhopadhyay et al.
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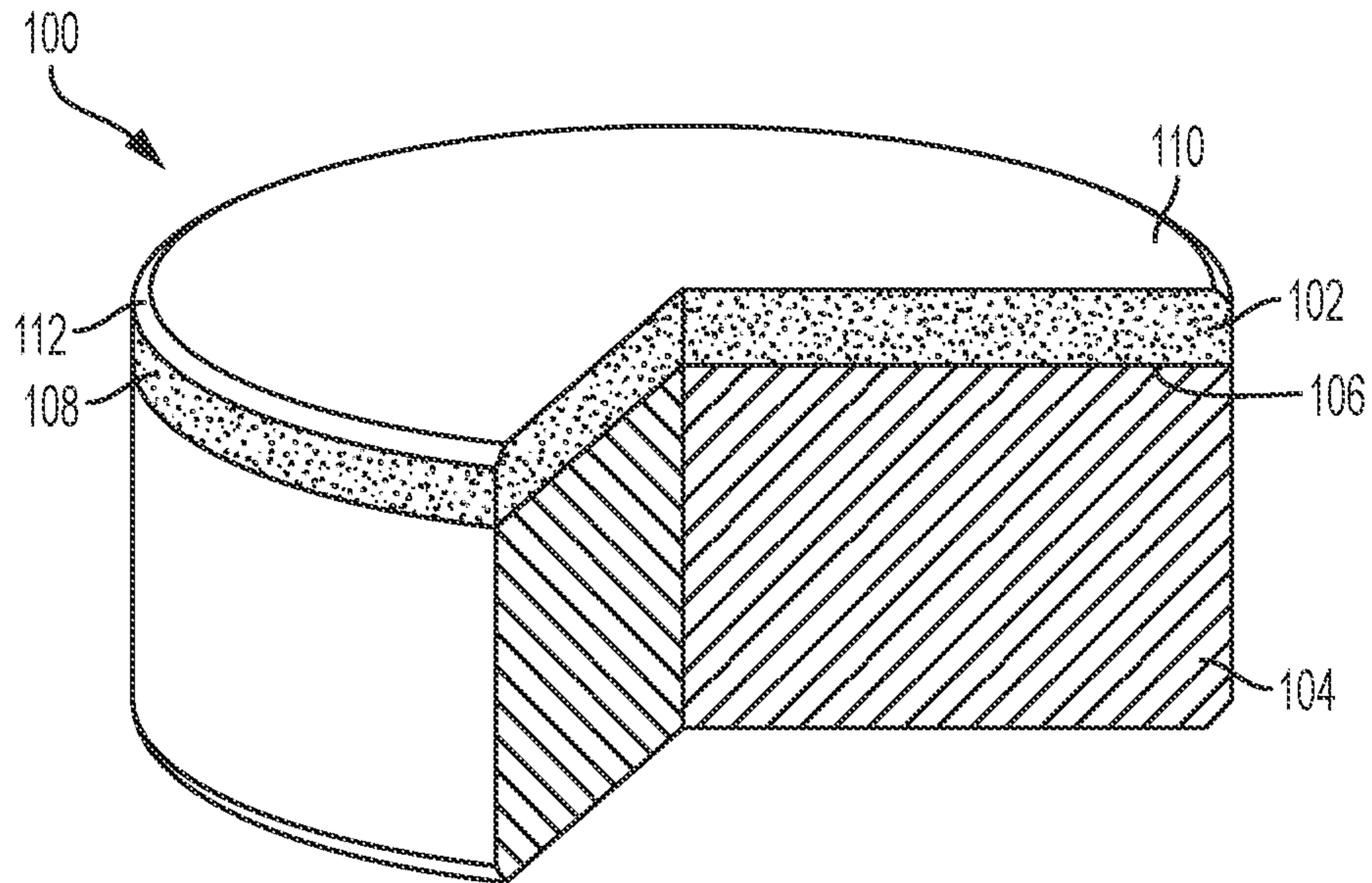


FIG. 1

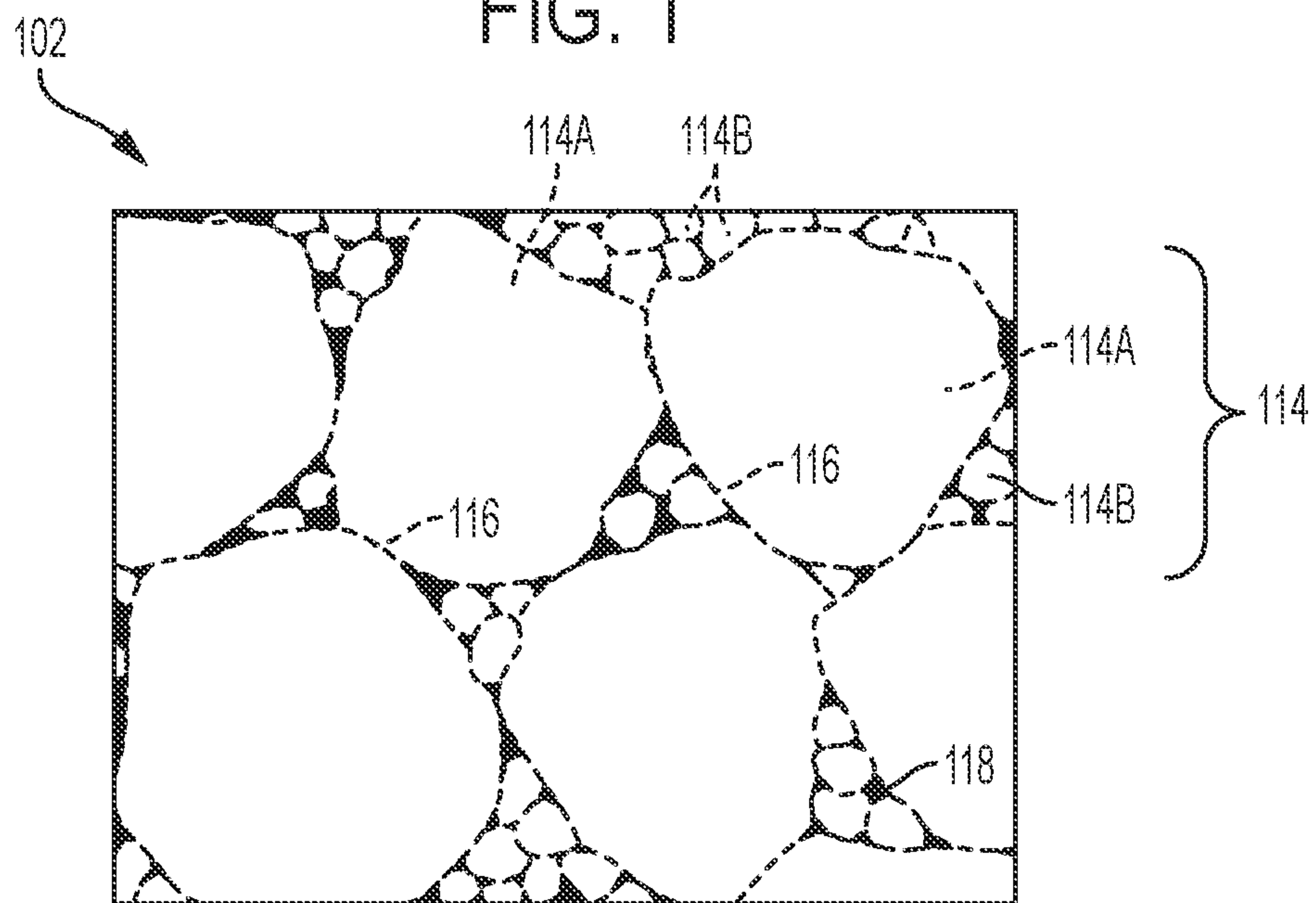


FIG. 2

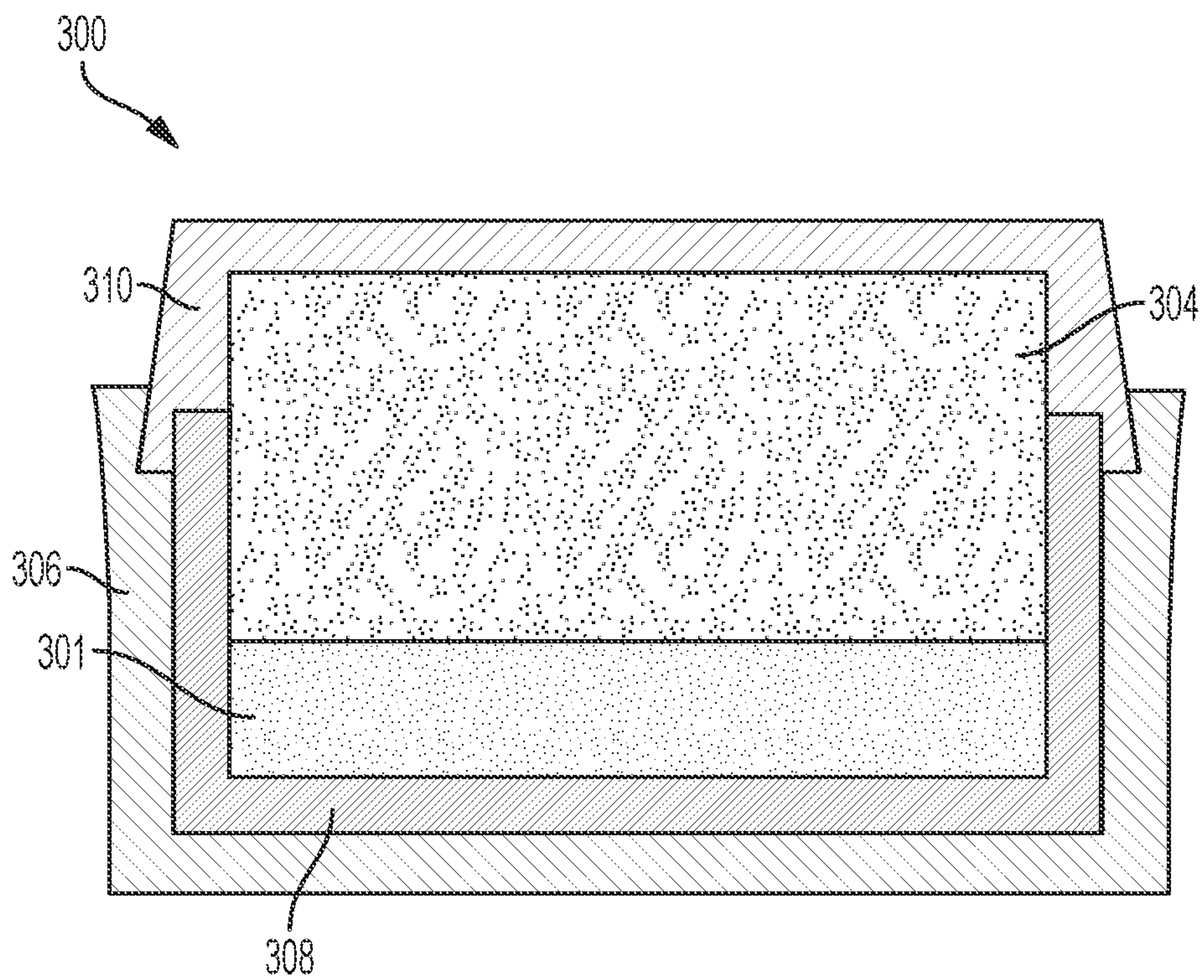


FIG. 3A

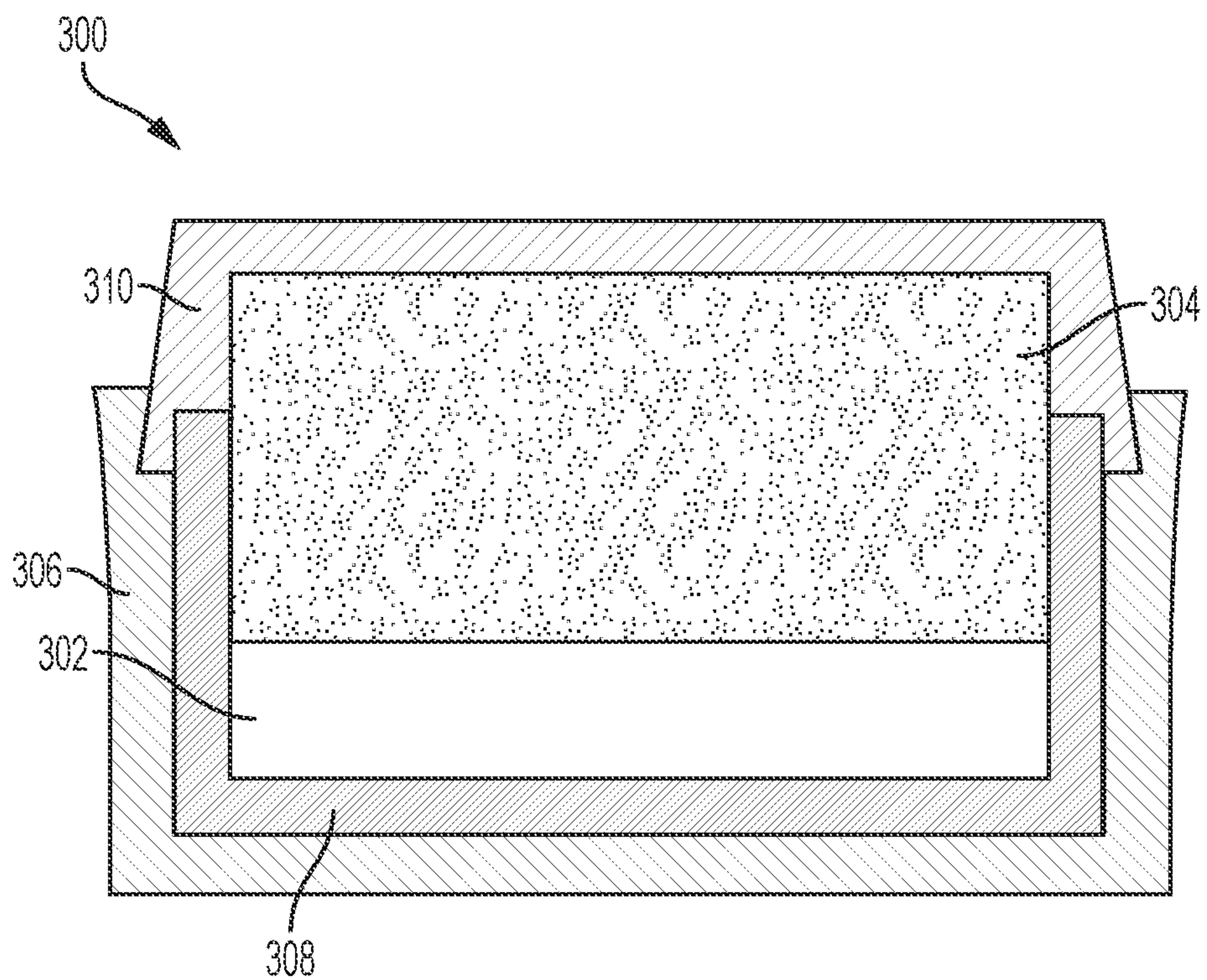


FIG. 3B



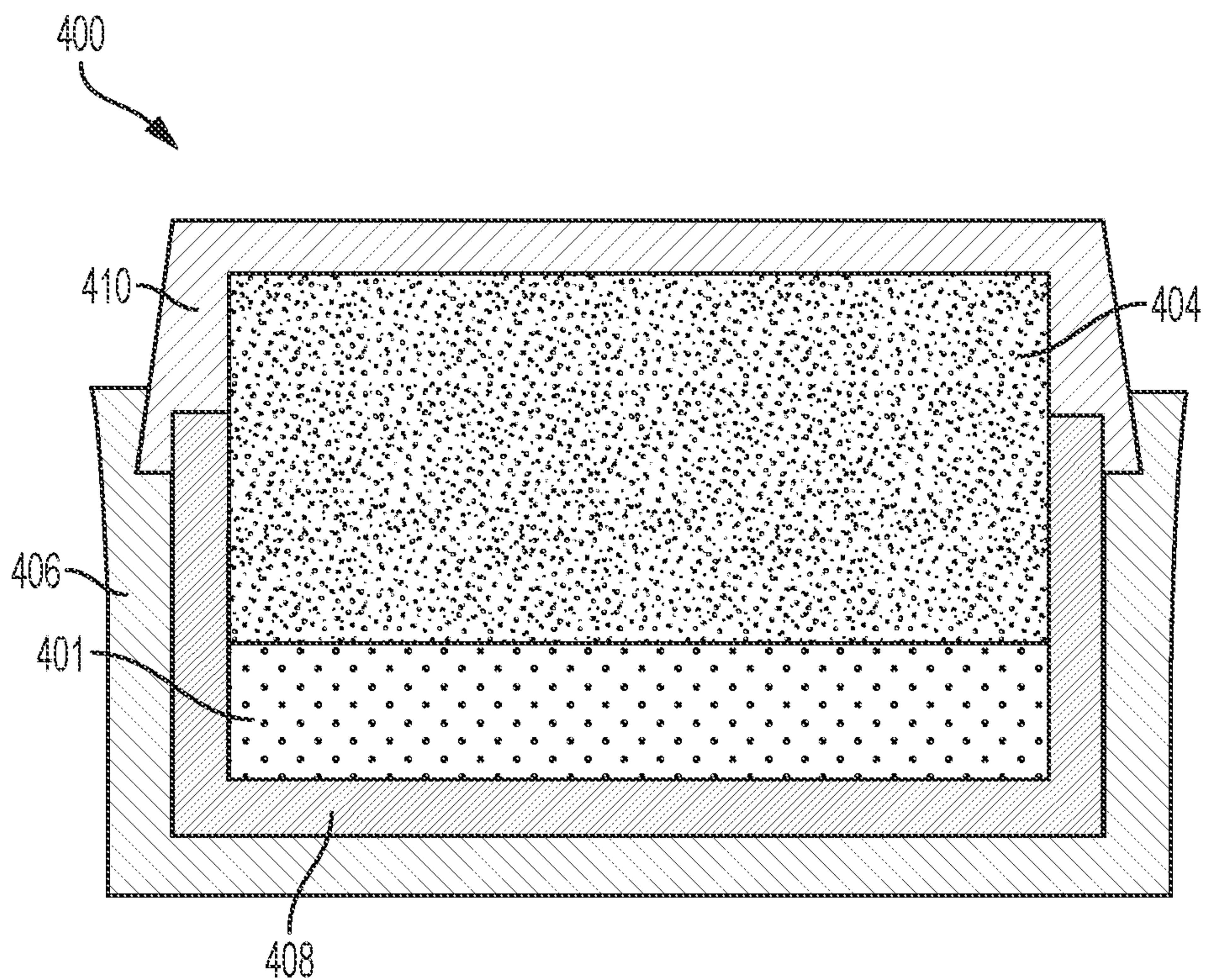


FIG. 4A

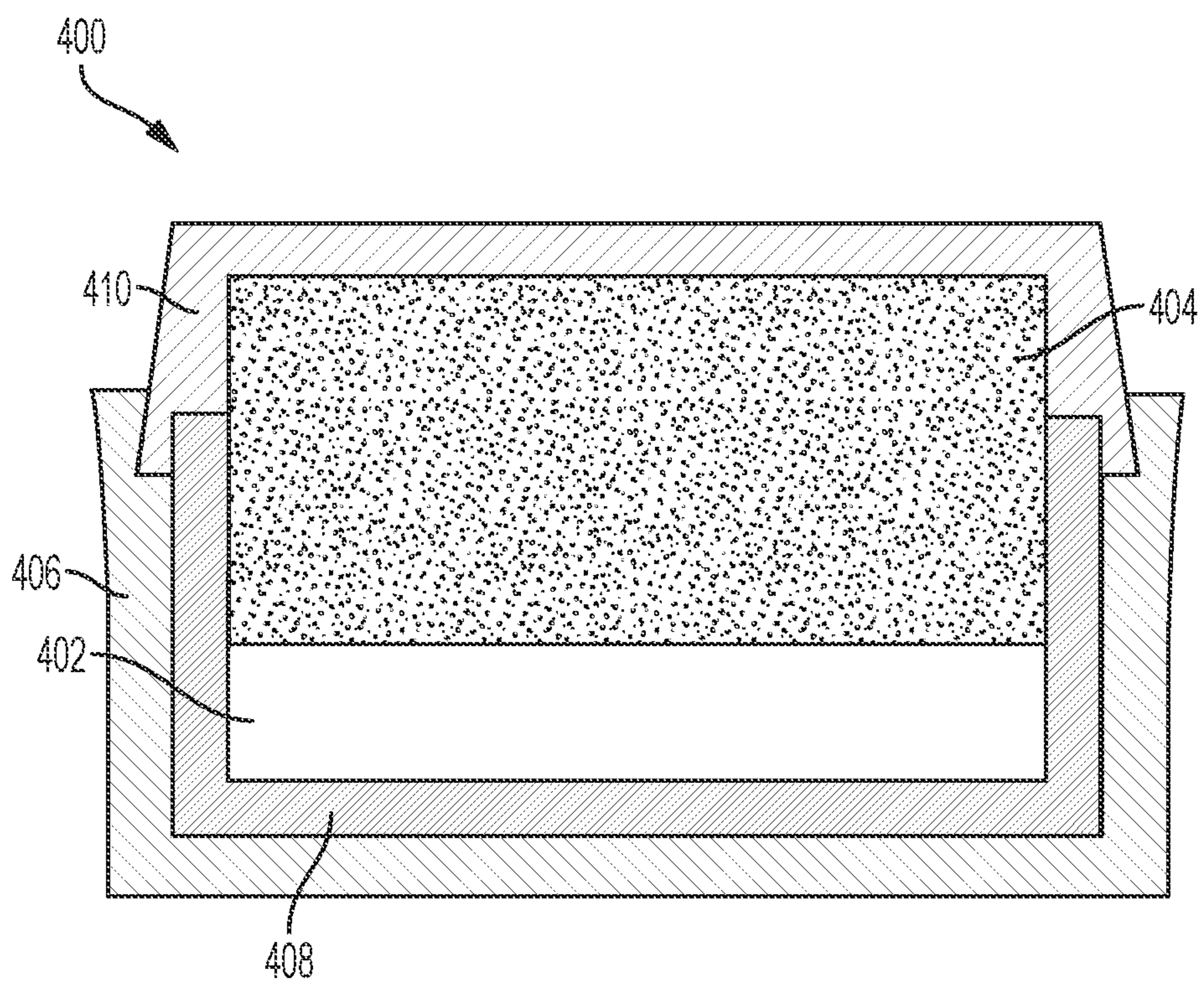


FIG. 4B



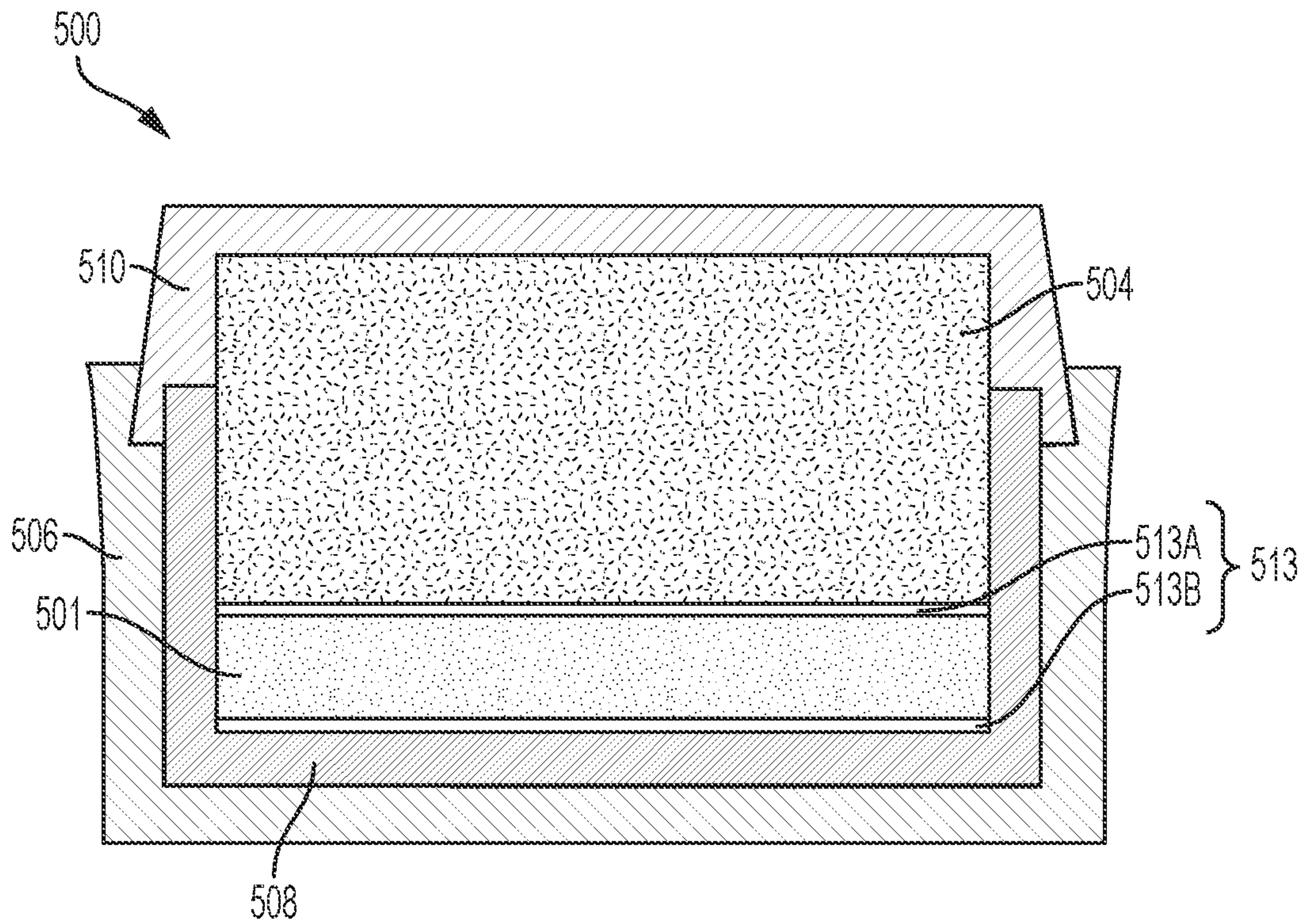


FIG. 5A

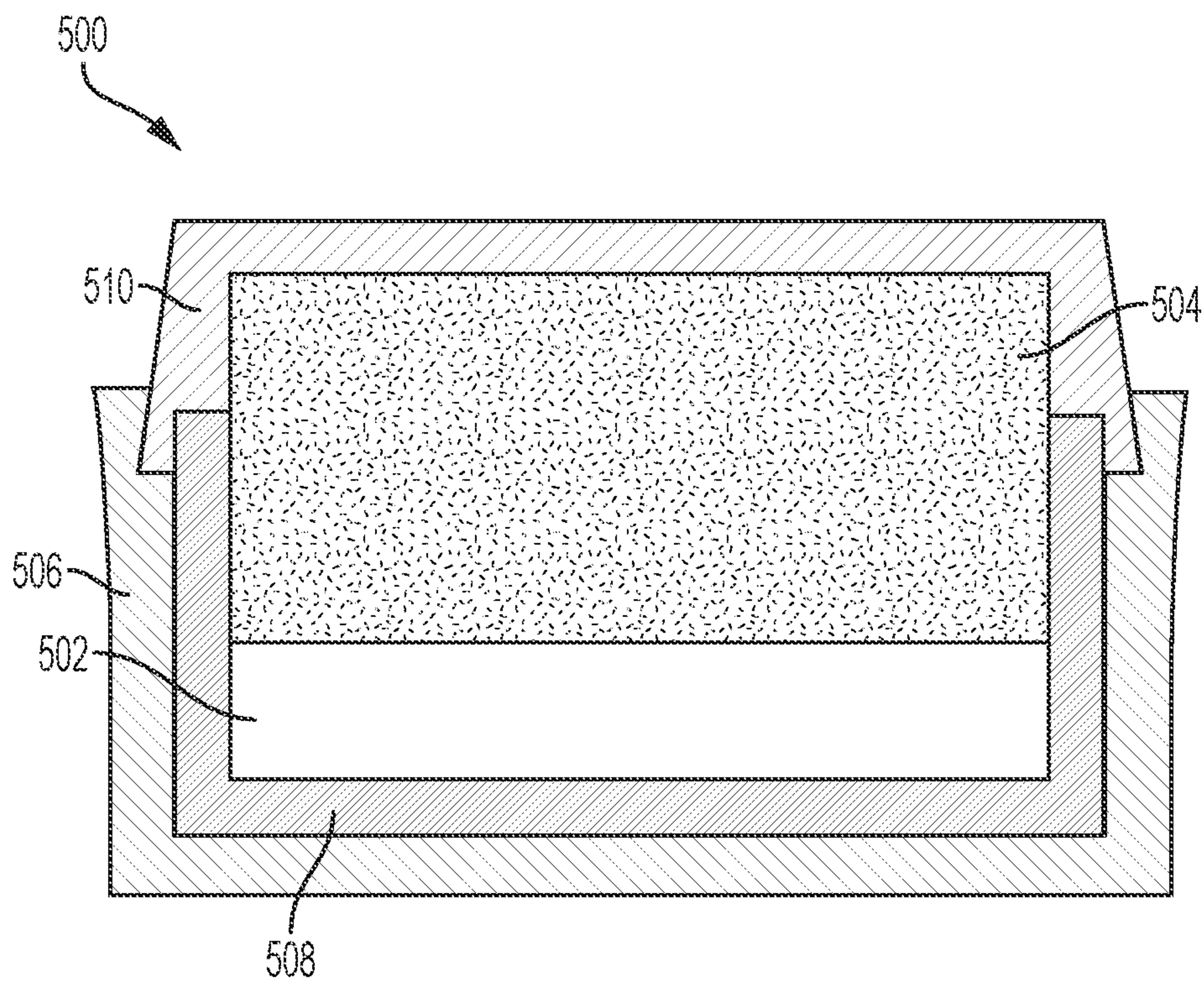


FIG. 5B



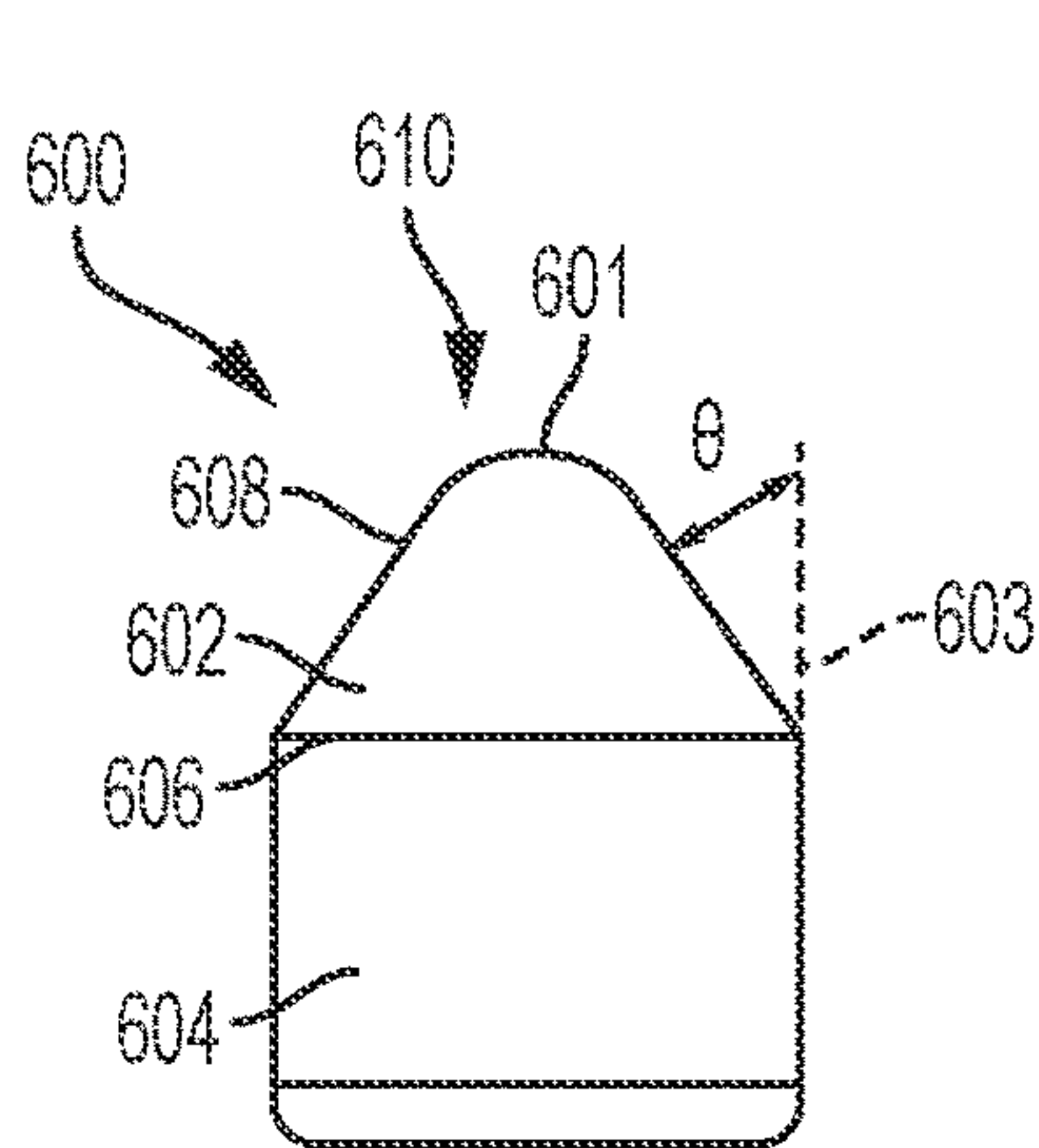


FIG. 6

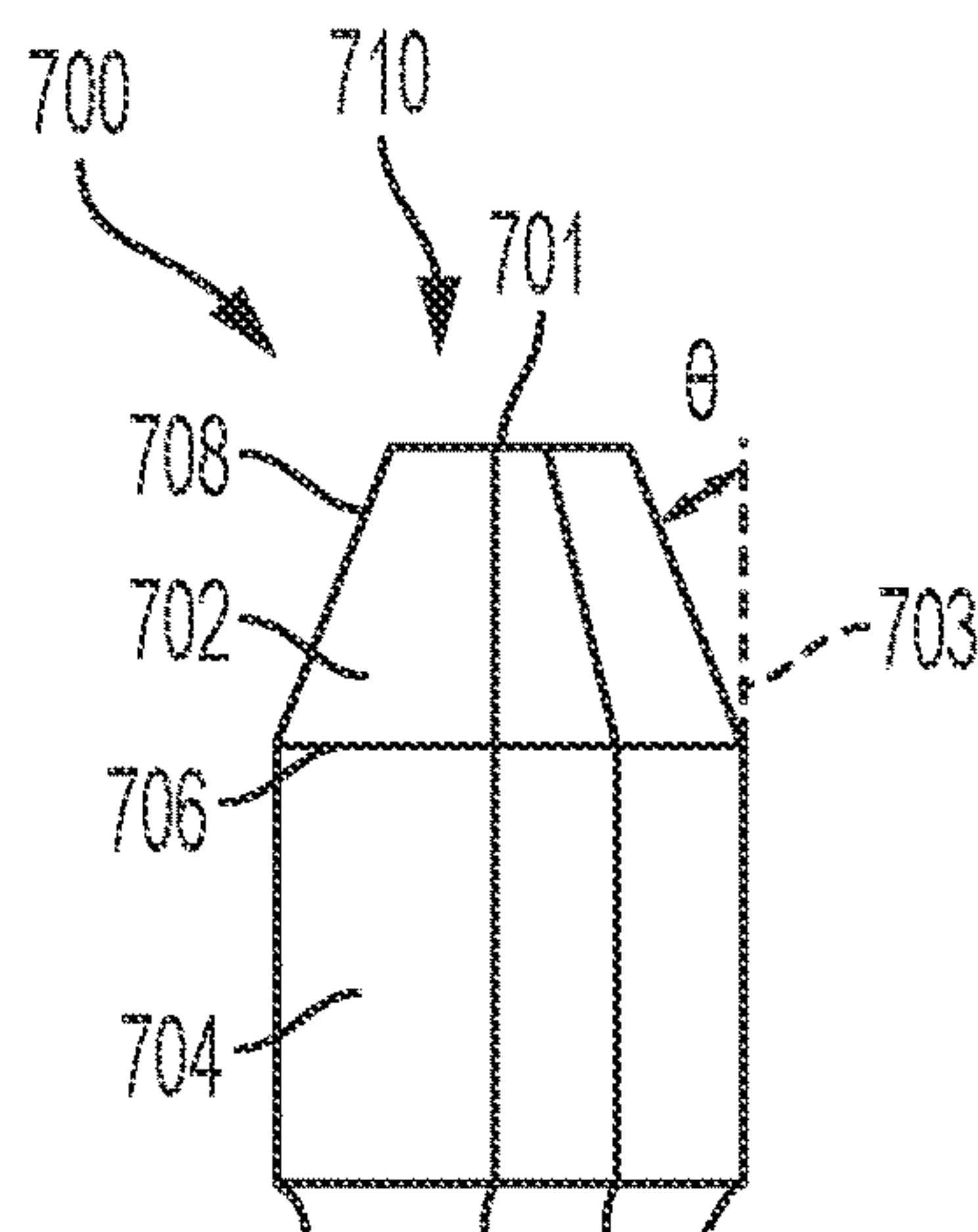


FIG. 7

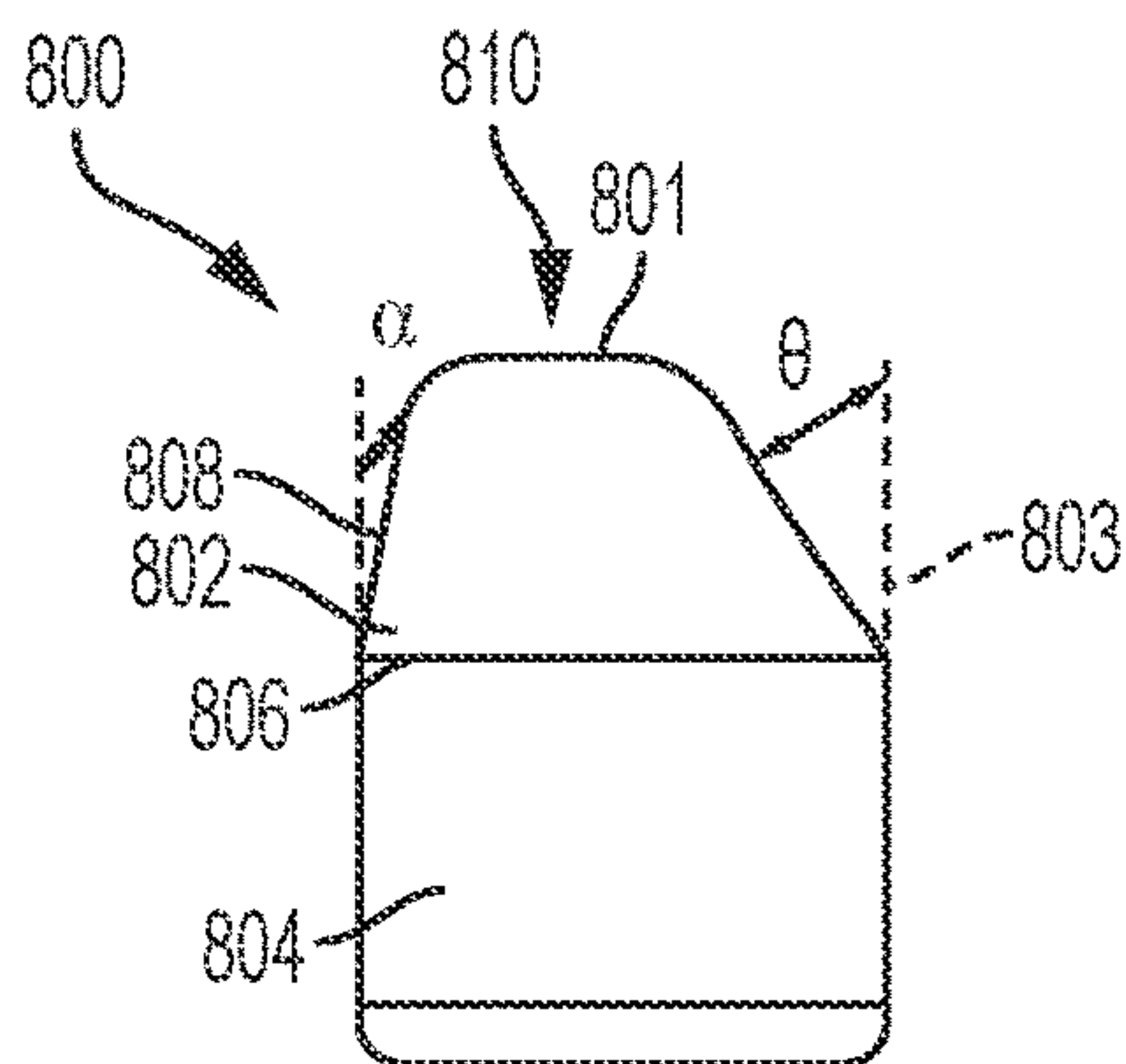


FIG. 8

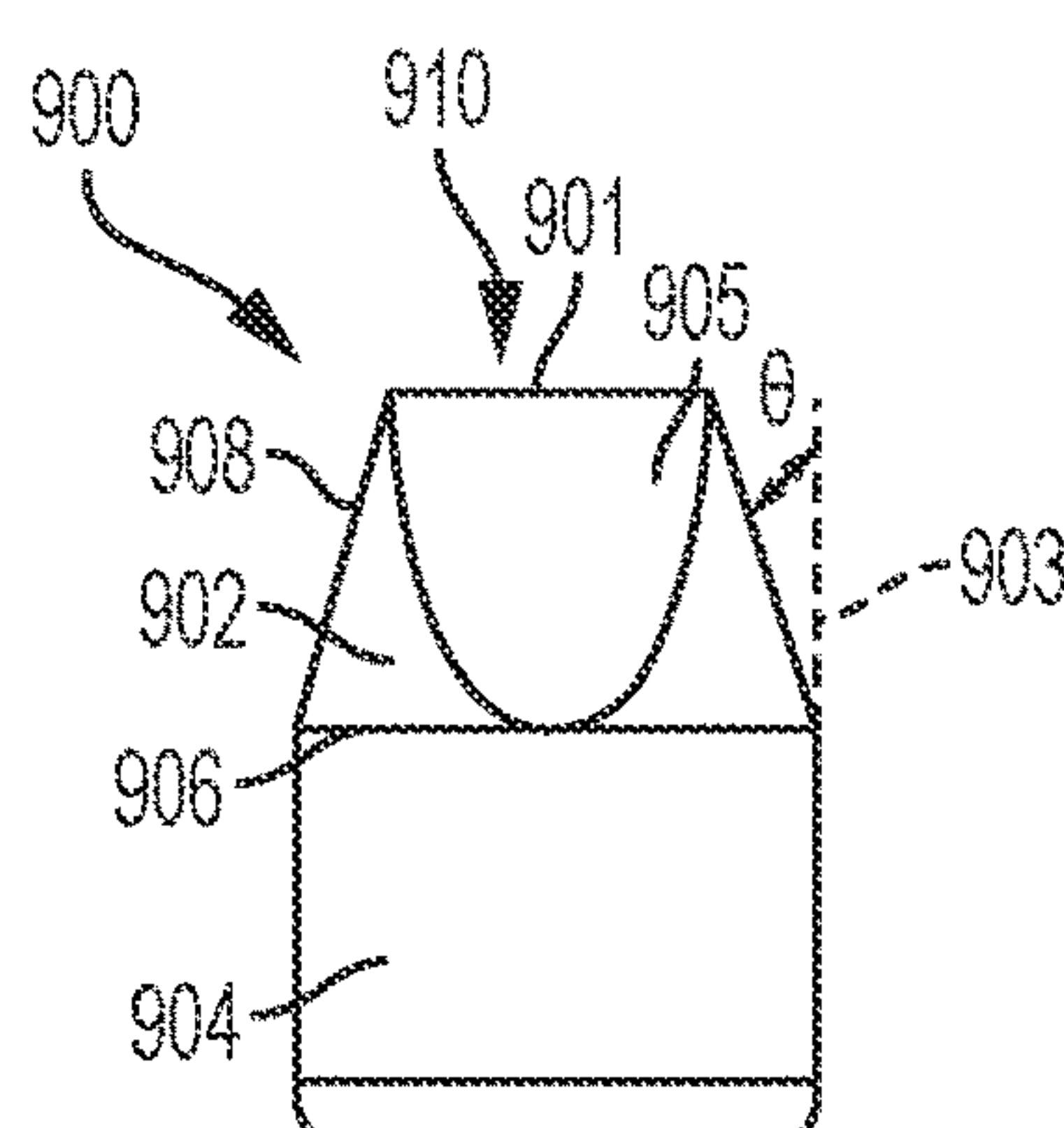


FIG. 9

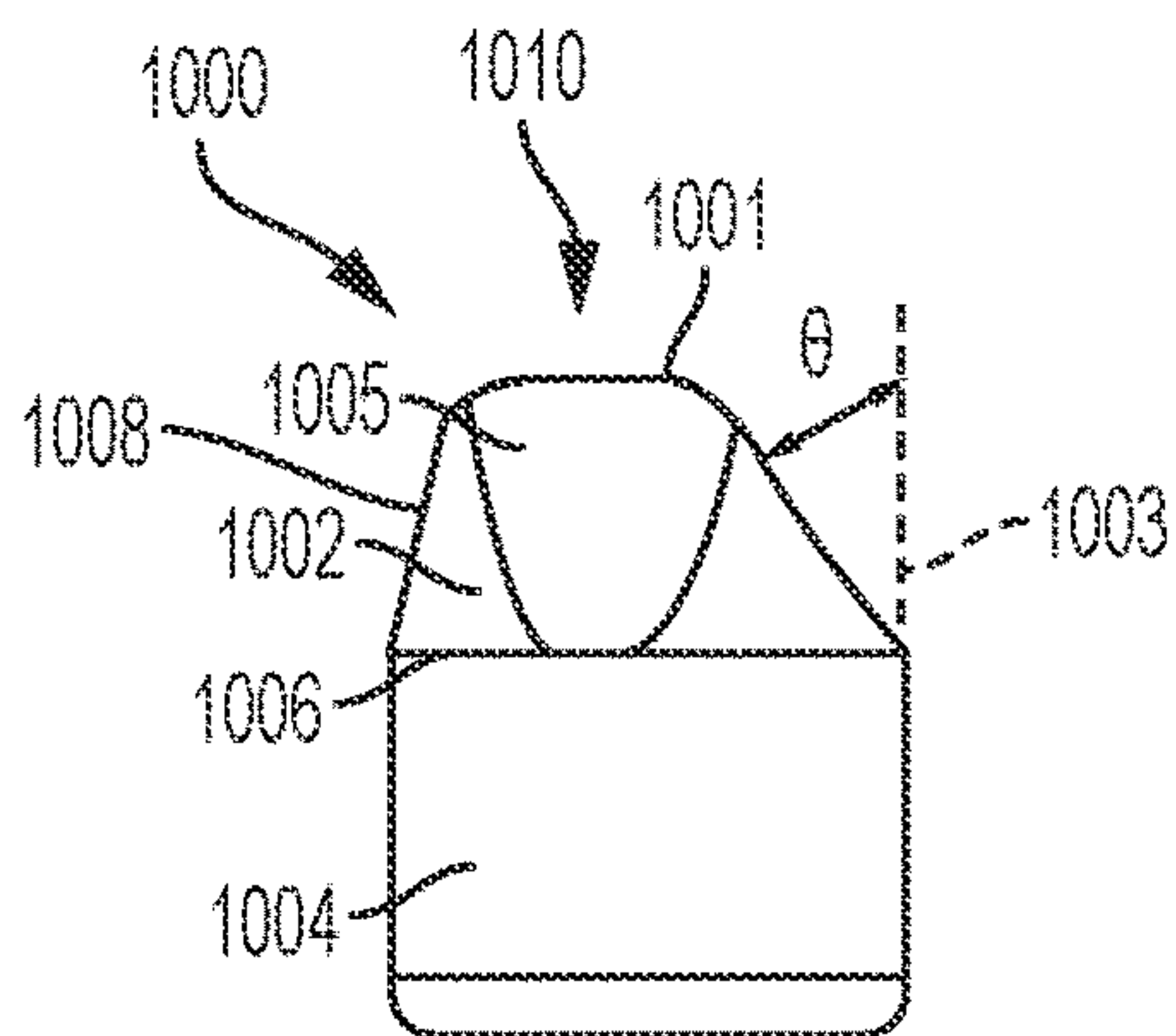


FIG. 10

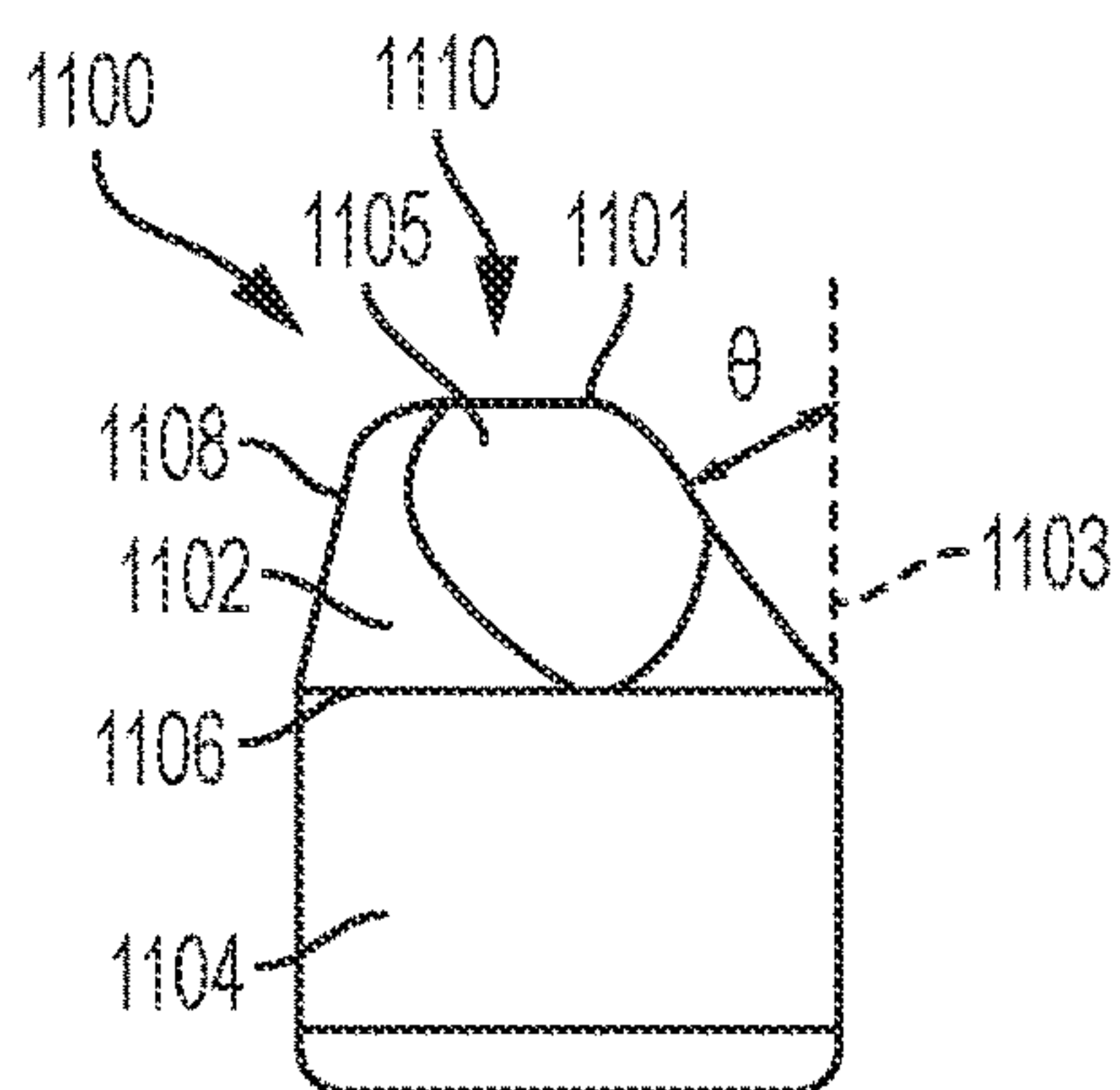


FIG. 11

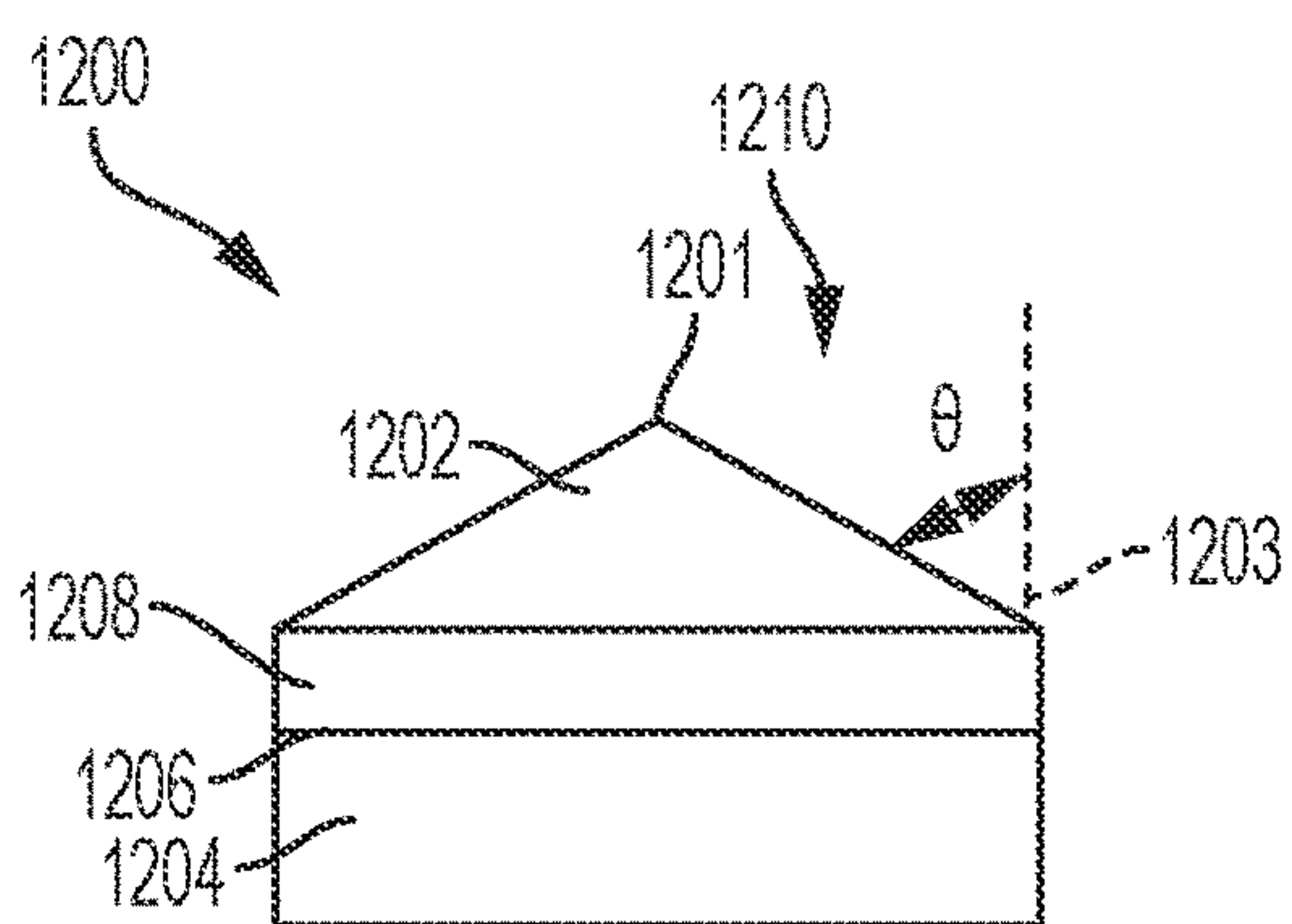


FIG. 12

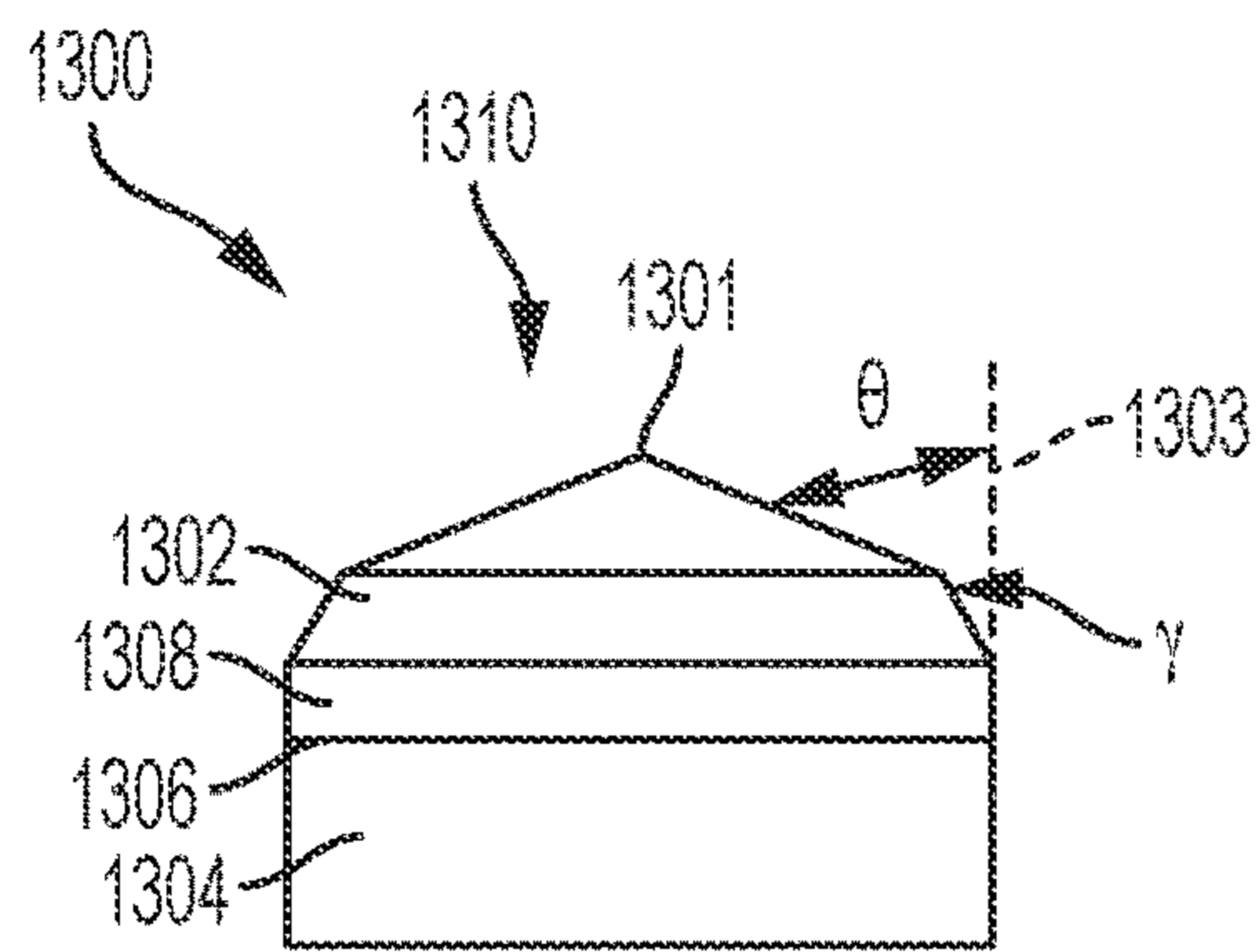


FIG. 13

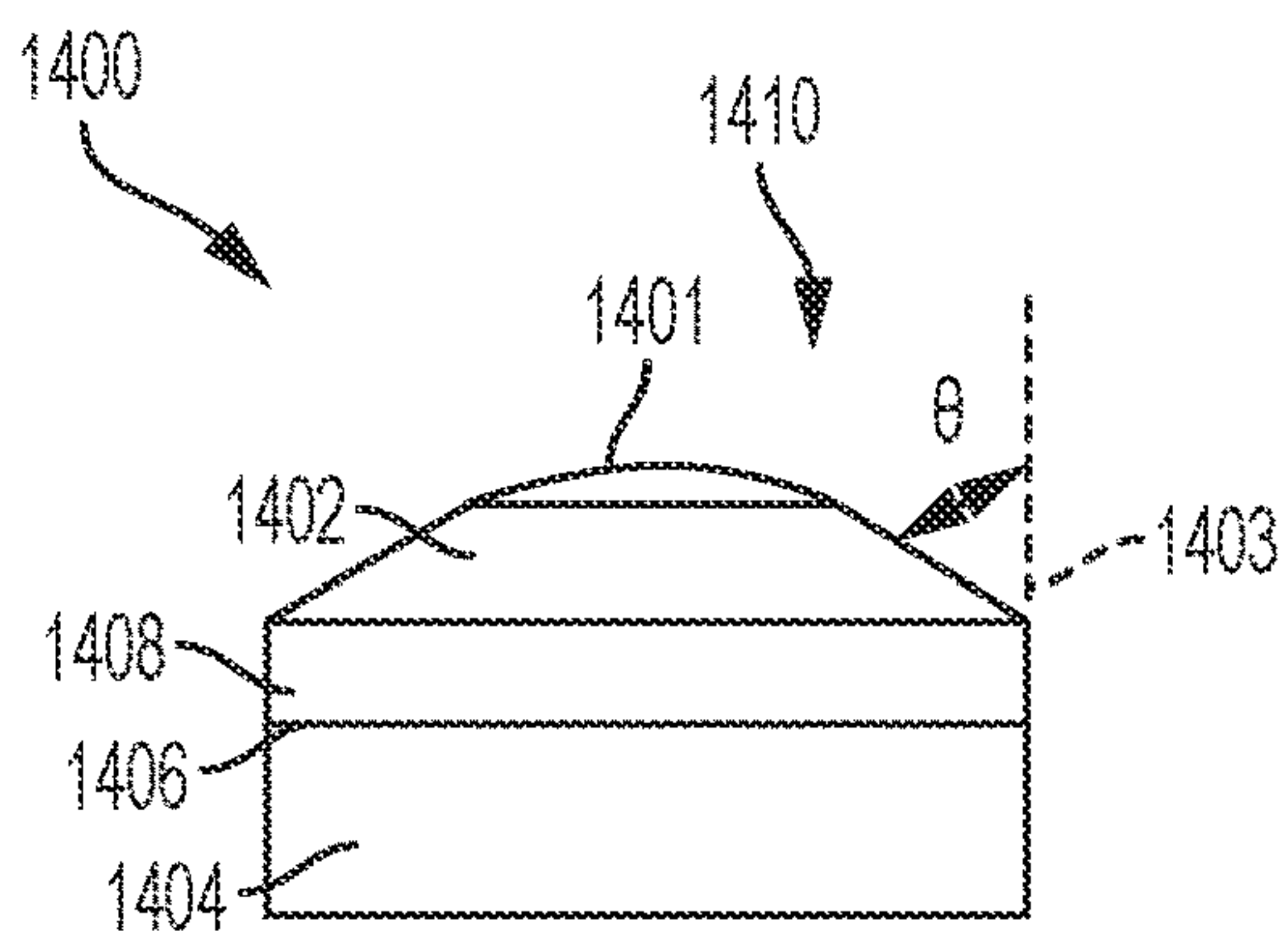


FIG. 14

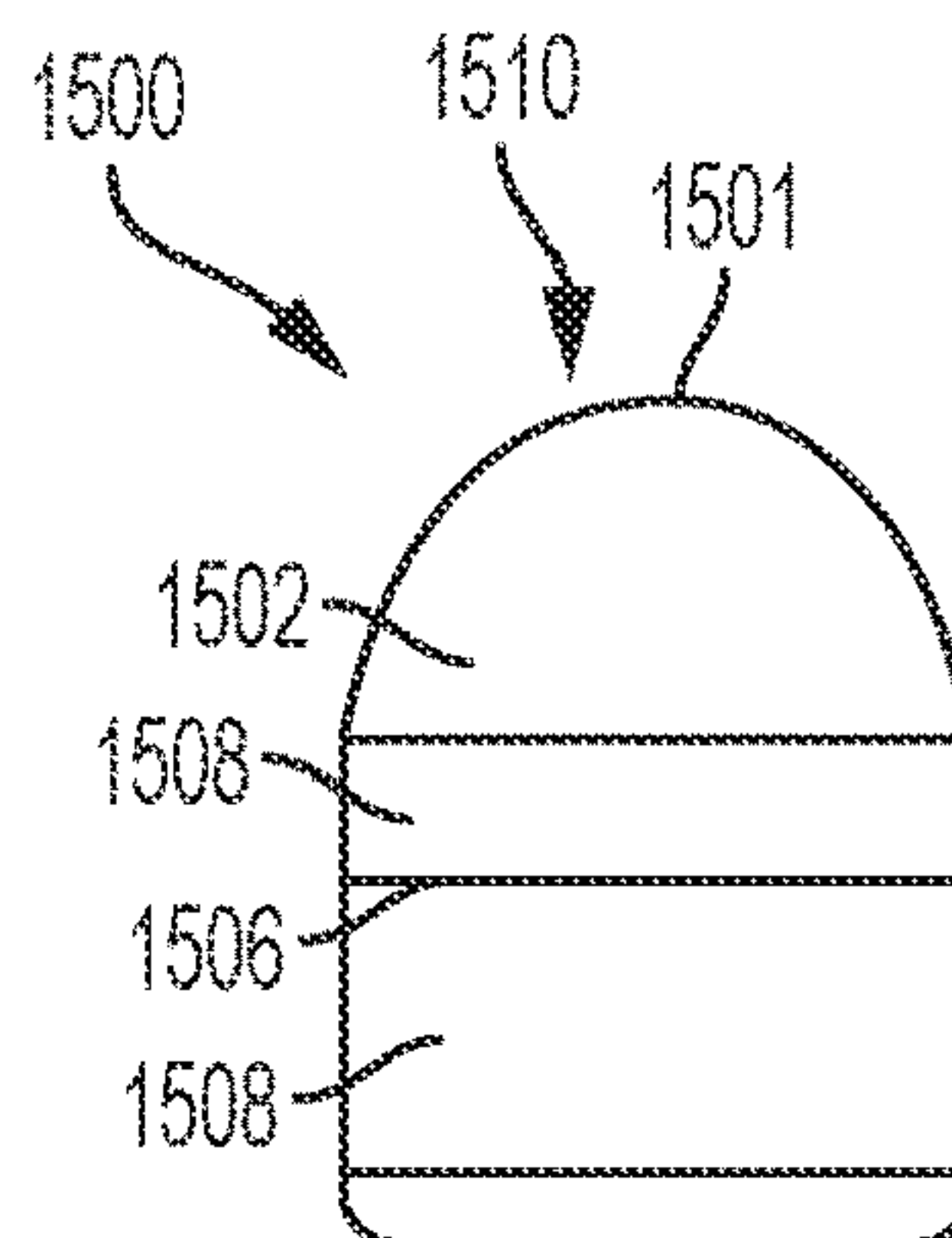


FIG. 15

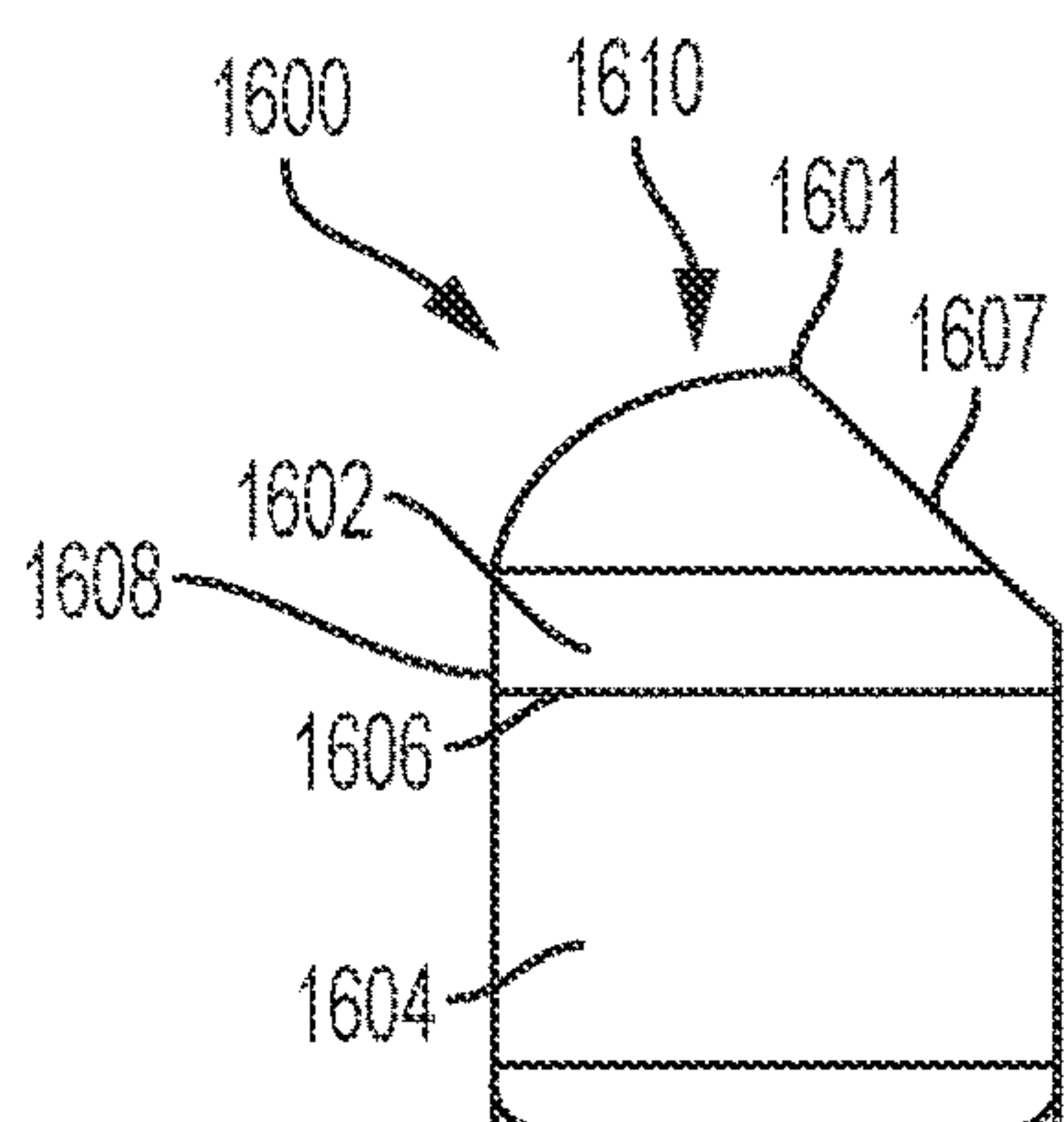


FIG. 16

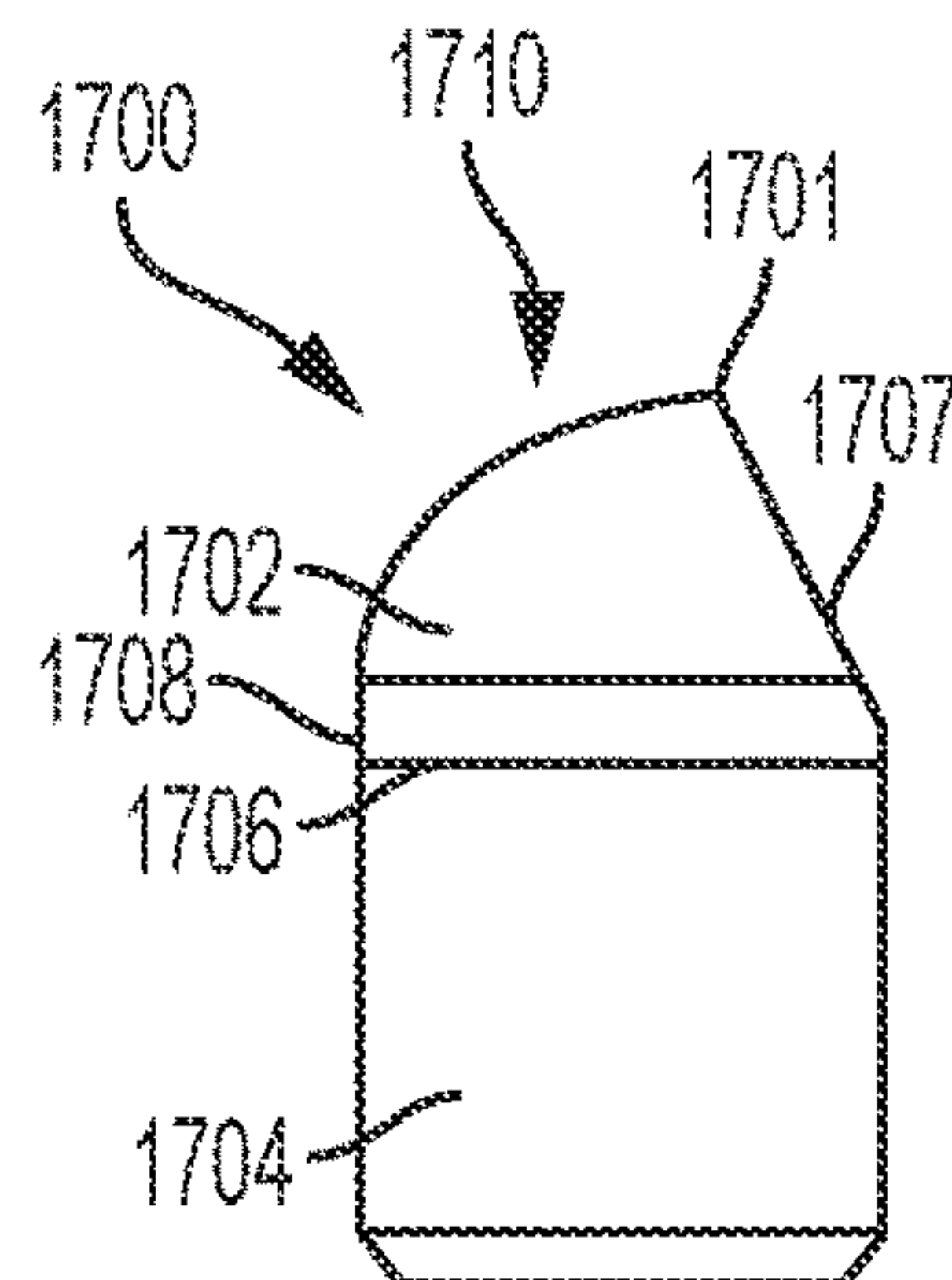


FIG. 17



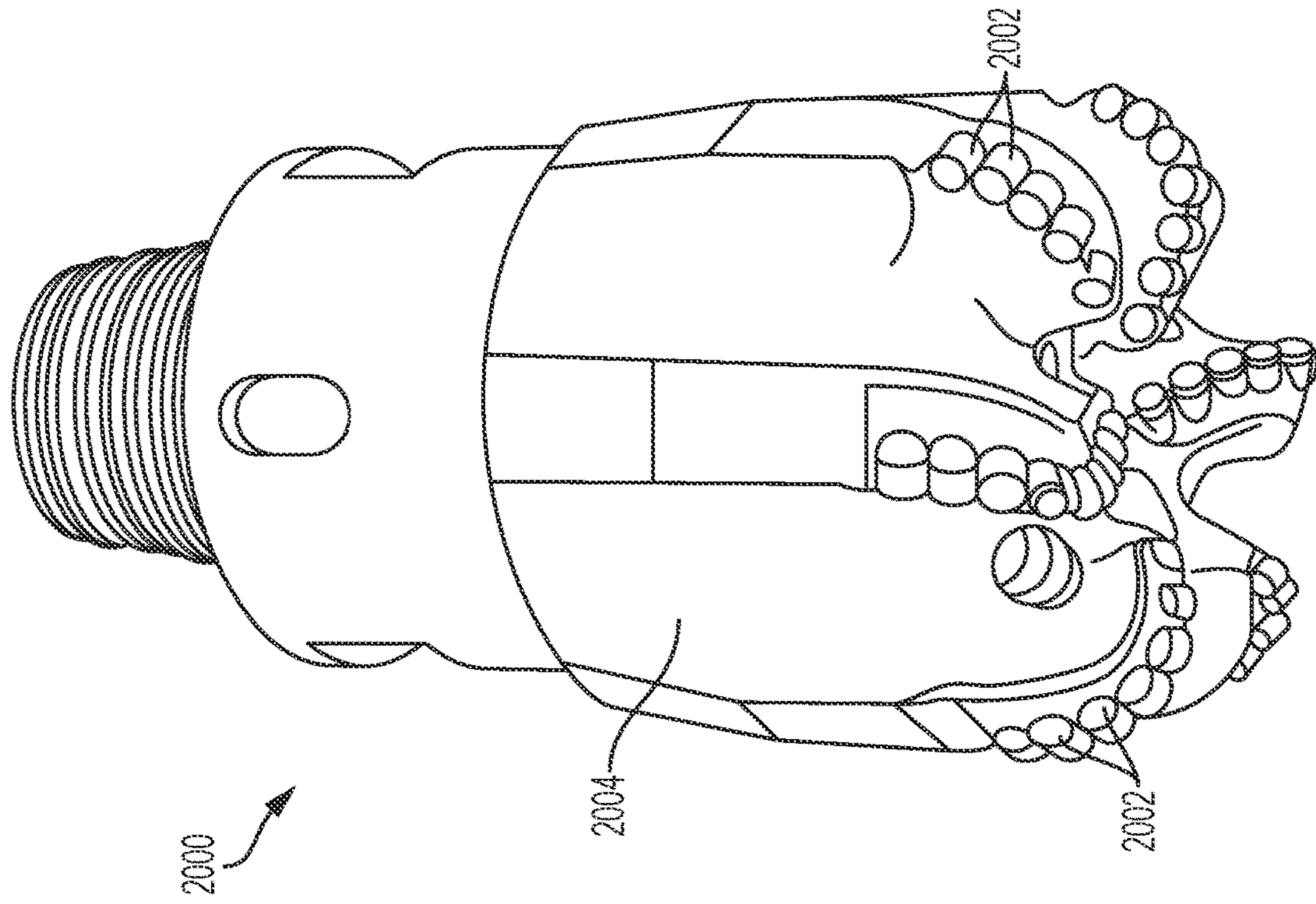


FIG. 20

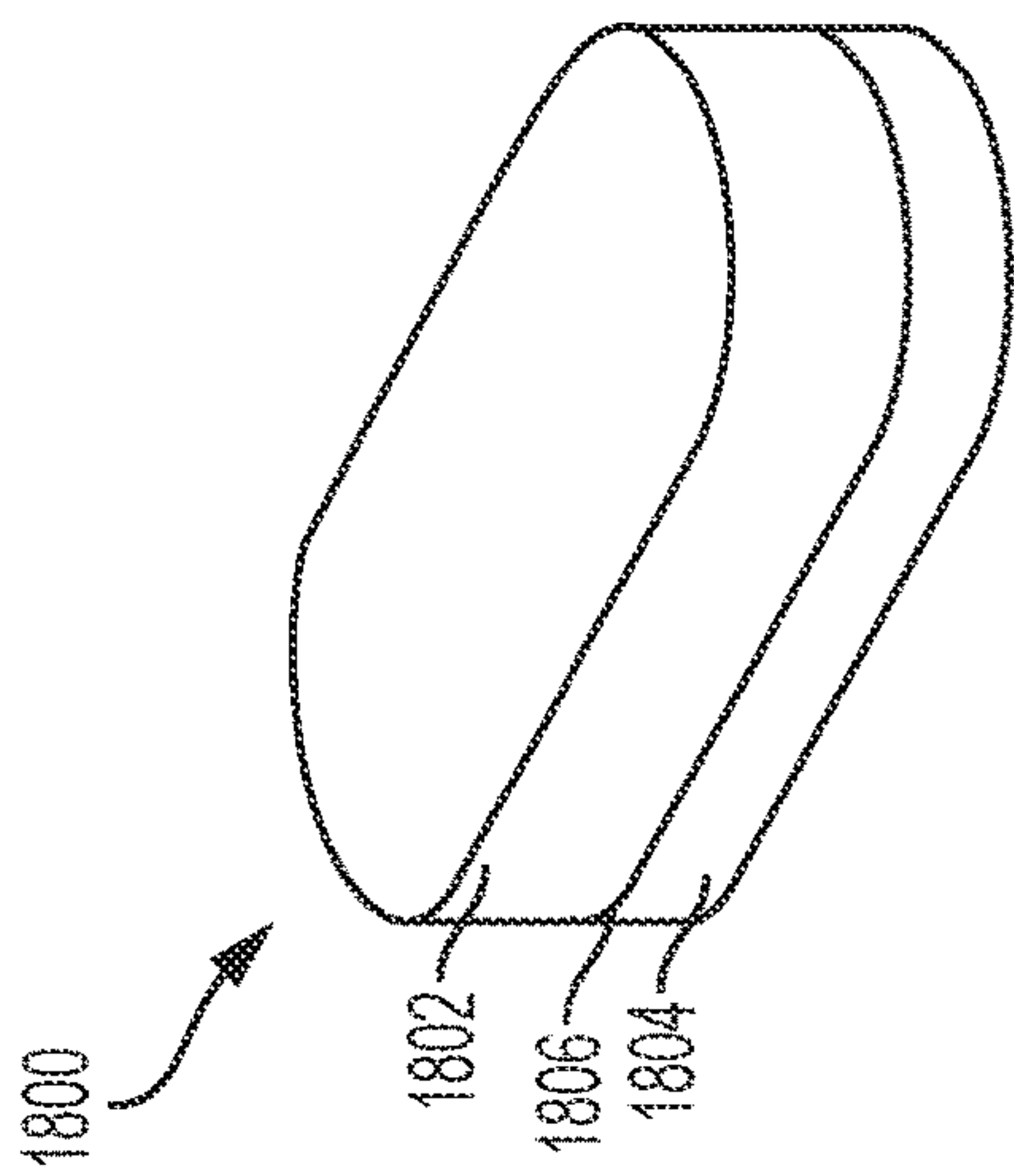


FIG. 18

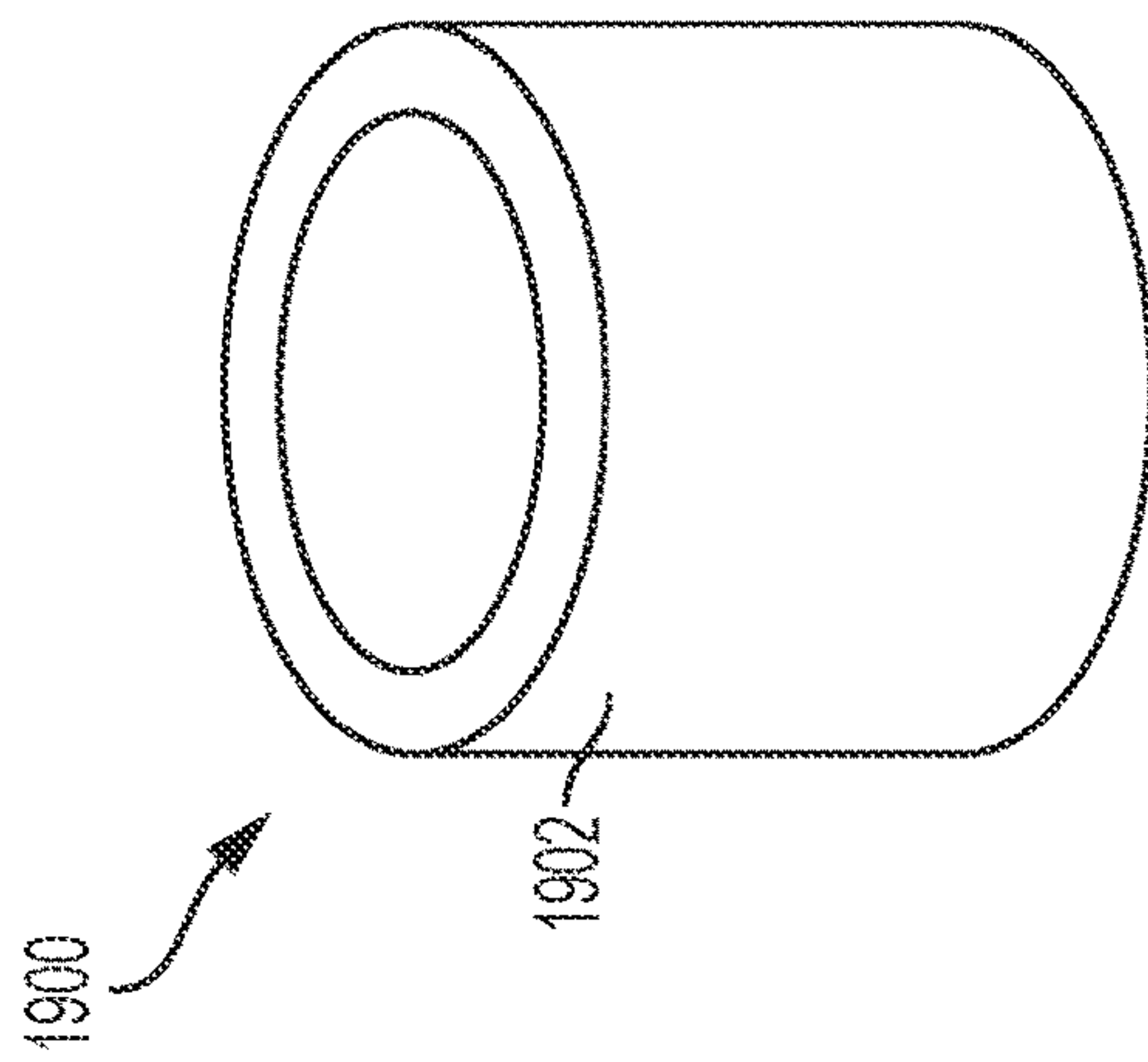


FIG. 19

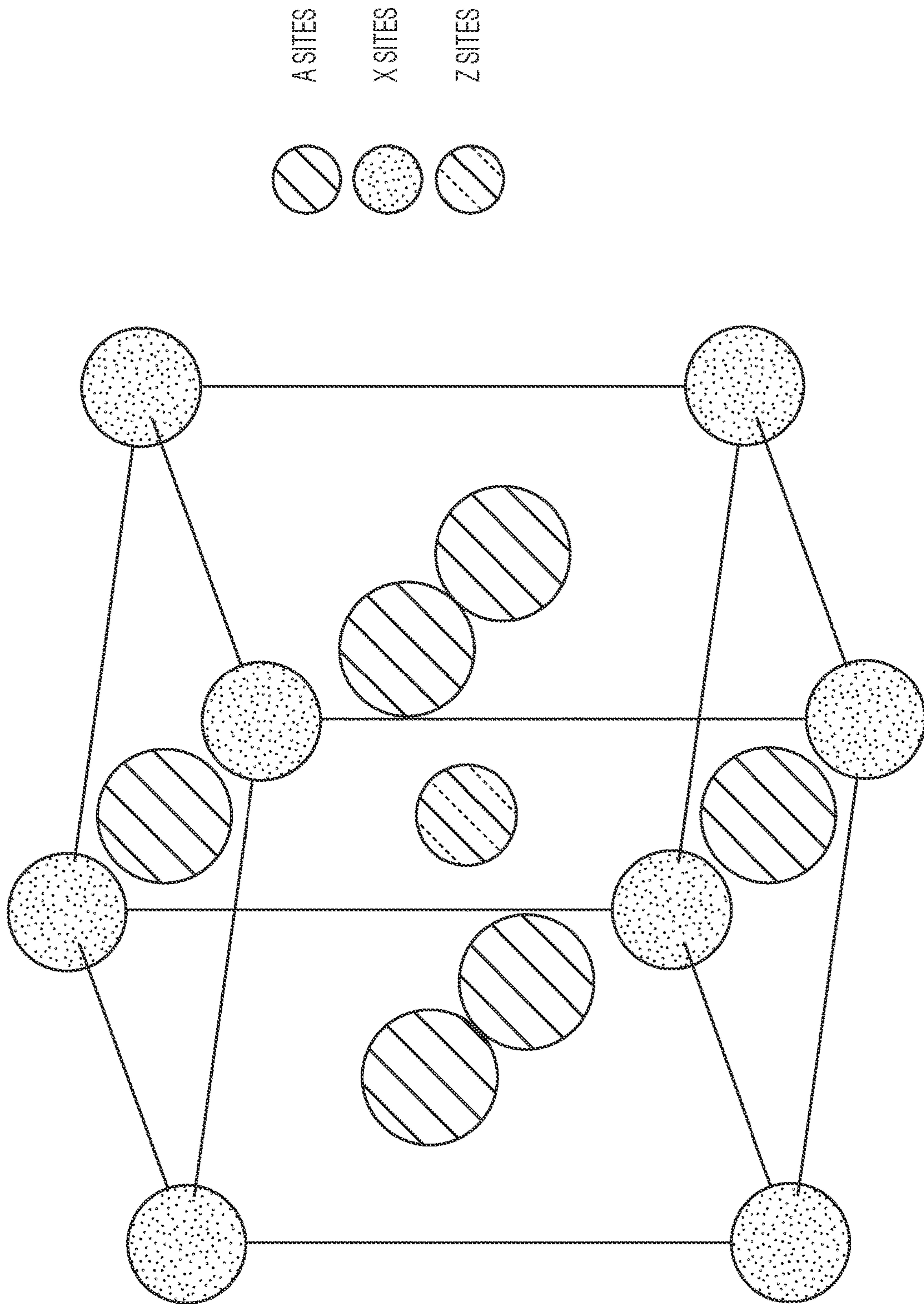


FIG. 21



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## CUTTING ELEMENTS, AND RELATED EARTH-BORING TOOLS, SUPPORTING SUBSTRATES, AND METHODS

### CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. patent application Ser. No. 15/993,362, filed May 30, 2018, the disclosure of which is hereby incorporated herein in its entirety by this reference.

### TECHNICAL FIELD

Embodiments of the disclosure relate to cutting elements, and to related earth-boring tools, structures, supporting substrates, and methods of forming the cutting elements, structures, and supporting substrates.

### BACKGROUND

Earth-boring tools for forming wellbores in subterranean earth formations may include a plurality of cutting elements secured to a body. For example, fixed-cutter earth-boring rotary drill bits (“drag bits”) include a plurality of cutting elements that are fixedly attached to a bit body of the drill bit. Similarly, roller cone earth-boring rotary drill bits may include cones that are mounted on bearing pins extending from legs of a bit body such that each cone is capable of rotating about the bearing pin on which it is mounted. A plurality of cutting elements may be mounted to each cone of the drill bit. Other earth-boring tools utilizing cutting elements include, for example, core bits, bi-center bits, eccentric bits, hybrid bits (e.g., rolling components in combination with fixed cutting elements), reamers, and casing milling tools.

The cutting elements used in such earth-boring tools often include a volume of polycrystalline diamond (“PCD”) material on a substrate. Surfaces of the polycrystalline diamond act as cutting faces of the so-called polycrystalline diamond compact (“PDC”) cutting elements. PCD material is material that includes inter-bonded particles (e.g., grains, crystals) of diamond material. In other words, PCD material includes direct, inter-granular bonds between the particles of diamond material.

PDC cutting elements are generally formed by sintering and bonding together relatively small diamond (synthetic, natural or a combination) particles, termed “grit,” under conditions of high temperature and high pressure in the presence of a catalyst (e.g., cobalt, iron, nickel, or alloys and mixtures thereof) to form one or more layers (e.g., a “compact” or “table”) of PCD material. These processes are often referred to as high temperature/high pressure (or “HTHP”) processes. The supporting substrate may comprise a cermet material (i.e., a ceramic-metal composite material) such as, for example, cobalt-cemented tungsten carbide. In some instances, the PCD material may be formed on the cutting element, for example, during the HTHP process. In such instances, catalyst material (e.g., cobalt) in the supporting substrate may be “swept” into the diamonds during sintering and serve as a catalyst material for forming the diamond table from the diamond particles. Powdered catalyst material may also be mixed with the diamond particles prior to sintering the particles together in an HTHP process. In other methods, the diamond table may be formed separately from the supporting substrate and subsequently attached thereto.

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Upon formation of the diamond table using an HTHP process, catalyst material may remain in interstitial spaces between the inter-bonded particles of the PDC. The presence of the catalyst material in the PDC may contribute to thermal damage in the PDC when the PDC cutting element is heated during use due to friction at the contact point between the cutting element and the formation. Accordingly, the catalyst material (e.g., cobalt) may be leached out of the interstitial spaces using, for example, an acid or combination of acids (e.g., aqua regia). Substantially all of the catalyst material may be removed from the PDC, or catalyst material may be removed from only a portion thereof, for example, from a cutting face of the PDC, from a side of the PDC, or both, to a desired depth. However, a fully leached PDC is relatively more brittle and vulnerable to shear, compressive, and tensile stresses than is a non-leached PDC. In addition, it is difficult to secure a completely leached PDC to a supporting substrate.

### BRIEF SUMMARY

Embodiments described herein include cutting elements, and related earth-boring tools, structures, supporting substrates, and methods of forming the cutting elements, structures, and supporting substrates. For example, in accordance with one embodiment described herein, a cutting element comprises a cutting table comprising inter-bonded diamond particles, and a thermally stable material within interstitial spaces between the inter-bonded diamond particles. The thermally stable material comprises a carbide precipitate having the general chemical formula,  $A_3XZ_{n-1}$ , where A comprises one or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U; X comprises one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P; Z comprises C; and n is greater than or equal to 0 and less than or equal to 0.75.

In additional embodiments, a method of forming a cutting element comprises providing a diamond-containing material comprising discrete diamond particles over a substrate. The diamond-containing material is sintered in the presence of a liquid phase of a homogenized alloy comprising at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U, and at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P to inter-bond the discrete diamond particles. Portions of the homogenized alloy within interstitial spaces between the inter-bonded diamond particles are converted into a thermally stable material comprising one or more carbide precipitates having the general chemical formula:  $A_3XZ_{1-n}$ , where A comprises the at least one first element; X comprises the at least one second element; Z comprises C; and n is greater than or equal to 0 and less than or equal to 0.75.

In further embodiments, a supporting substrate for a cutting element comprises a homogenized binder and WC particles dispersed in the homogenized binder. The homogenized binder comprises C, W, at least one element selected from Sc, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac,



Th, Pa, and U, and at least one additional element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial cut-away perspective view of a cutting element, in accordance with embodiments of the disclosure.

FIG. 2 is a simplified cross-sectional view illustrating how a microstructure of a cutting table of the cutting element of FIG. 1 may appear under magnification.

FIGS. 3A and 3B are simplified cross-sectional views of a container in a process of forming a cutting element, in accordance with embodiments of the disclosure.

FIGS. 4A and 4B are simplified cross-sectional views of a container in a process of forming a cutting element, in accordance with additional embodiments of the disclosure.

FIGS. 5A and 5B are simplified cross-sectional views of a container in a process of forming a cutting element, in accordance with further embodiments of the disclosure.

FIGS. 6 through 17 are side elevation views of different cutting elements, in accordance with additional embodiments of the disclosure.

FIG. 18 is a perspective view of a bearing structure, in accordance with embodiments of the disclosure.

FIG. 19 is a perspective view of a die structure, in accordance with embodiments of the disclosure.

FIG. 20 is a perspective view of an embodiment of a fixed-cutter earth-boring rotary drill bit including a cutting element of the disclosure.

FIG. 21 is a simplified perspective view of the lattice structure of a  $\kappa$ -carbide precipitate of the cutting table of the cutting element of FIG. 1.

### DETAILED DESCRIPTION

The following description provides specific details, such as specific shapes, specific sizes, specific material compositions, and specific processing conditions, in order to provide a thorough description of embodiments of the present disclosure. However, a person of ordinary skill in the art would understand that the embodiments of the disclosure may be practiced without necessarily employing these specific details. Embodiments of the disclosure may be practiced in conjunction with conventional fabrication techniques employed in the industry. In addition, the description provided below does not form a complete process flow for manufacturing a cutting element or earth-boring tool. Only those process acts and structures necessary to understand the embodiments of the disclosure are described in detail below. Additional acts to form a complete cutting element or a complete earth-boring tool from the structures described herein may be performed by conventional fabrication processes.

Drawings presented herein are for illustrative purposes only, and are not meant to be actual views of any particular material, component, structure, device, or system. Variations from the shapes depicted in the drawings as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, embodiments described herein are not to be construed as being limited to the particular shapes or regions as illustrated, but include deviations in shapes that result, for example, from manufacturing. For example, a region illustrated or described as box-shaped may have rough and/or nonlinear features, and a region illustrated or described as round may include some rough and/or linear features. Moreover, sharp angles that are illustrated may be rounded, and vice versa. Thus, the regions illustrated in the

figures are schematic in nature, and their shapes are not intended to illustrate the precise shape of a region and do not limit the scope of the present claims. The drawings are not necessarily to scale. Additionally, elements common

5 between figures may retain the same numerical designation.

As used herein, the terms “comprising,” “including,” “having,” and grammatical equivalents thereof are inclusive or open-ended terms that do not exclude additional, unrecited elements or method steps, but also include the more restrictive terms “consisting of” and “consisting essentially of” and grammatical equivalents thereof. As used herein, the term “may” with respect to a material, structure, feature, or method act indicates that such is contemplated for use in implementation of an embodiment of the disclosure and such term is used in preference to the more restrictive term “is” so as to avoid any implication that other, compatible materials, structures, features, and methods usable in combination therewith should or must be excluded.

As used herein, the terms “longitudinal,” “vertical,” “lateral,” and “horizontal” and are in reference to a major plane of a substrate (e.g., base material, base structure, base construction, etc.) in or on which one or more structures and/or features are formed and are not necessarily defined by earth’s gravitational field. A “lateral” or “horizontal” direction is a direction that is substantially parallel to the major plane of the substrate, while a “longitudinal” or “vertical” direction is a direction that is substantially perpendicular to the major plane of the substrate. The major plane of the substrate is defined by a surface of the substrate having a relatively large area compared to other surfaces of the substrate.

As used herein, spatially relative terms, such as “below,” “lower,” “bottom,” “above,” “over,” “upper,” “top,” and the like, may be used for ease of description to describe one element’s or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. Unless otherwise specified, the spatially relative terms are intended to encompass different orientations of the materials in addition to the orientation depicted in the figures. For example, if materials in the figures are inverted, elements described as “over” or “above” or “on” or “on top of” other elements or features would then be oriented “below” or “beneath” or “under” or “on bottom of” the other elements or features. Thus, the term “over” can encompass both an orientation of above and below, depending on the context in which the term is used, which will be evident to one of ordinary skill in the art. The materials may be otherwise oriented (e.g., rotated 90 degrees, inverted, flipped) and the spatially relative descriptors used herein interpreted accordingly.

As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise.

As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

As used herein, the term “configured” refers to a size, shape, material composition, material distribution, orientation, and arrangement of one or more of at least one structure and at least one apparatus facilitating operation of one or more of the structure and the apparatus in a predetermined way.

As used herein, the term “substantially” in reference to a given parameter, property, or condition means and includes to a degree that one of ordinary skill in the art would understand that the given parameter, property, or condition is met with a degree of variance, such as within acceptable tolerances. By way of example, depending on the particular parameter, property, or condition that is substantially met,



the parameter, property, or condition may be at least 90.0 percent met, at least 95.0 percent met, at least 99.0 percent met, at least 99.9 percent met, or even 100.0 percent met.

As used herein, “about” or “approximately” in reference to a numerical value for a particular parameter is inclusive of the numerical value and a degree of variance from the numerical value that one of ordinary skill in the art would understand is within acceptable tolerances for the particular parameter. For example, “about” or “approximately” in reference to a numerical value may include additional numerical values within a range of from 90.0 percent to 110.0 percent of the numerical value, such as within a range of from 95.0 percent to 105.0 percent of the numerical value, within a range of from 97.5 percent to 102.5 percent of the numerical value, within a range of from 99.0 percent to 101.0 percent of the numerical value, within a range of from 99.5 percent to 100.5 percent of the numerical value, or within a range of from 99.9 percent to 100.1 percent of the numerical value.

As used herein, the terms “earth-boring tool” and “earth-boring drill bit” mean and include any type of bit or tool used for drilling during the formation or enlargement of a well-bore in a subterranean formation and include, for example, fixed-cutter bits, roller cone bits, percussion bits, core bits, eccentric bits, bi-center bits, reamers, mills, drag bits, hybrid bits (e.g., rolling components in combination with fixed cutting elements), and other drilling bits and tools known in the art.

As used herein, the term “polycrystalline compact” means and includes any structure comprising a polycrystalline material formed by a process that involves application of pressure (e.g., compaction) to the precursor composition or materials used to form the polycrystalline material. In turn, as used herein, the term “polycrystalline material” means and includes any material comprising a plurality of particles (e.g., grains, crystals) of the material that are bonded directly together by inter-granular bonds. The crystal structures of the individual particles of the material may be randomly oriented in space within the polycrystalline material.

As used herein, the term “inter-granular bond” means and includes any direct atomic bond (e.g., covalent, metallic, etc.) between atoms in adjacent particles of hard material.

As used herein, the term “hard material” means and includes any material having a Knoop hardness value of greater than or equal to about 3,000 Kg/mm<sup>2</sup> (29, 420 MPa). Non-limiting examples of hard materials include diamond (e.g., natural diamond, synthetic diamond, or combinations thereof), and cubic boron nitride.

FIG. 1 illustrates a cutting element 100 in accordance with embodiments of the disclosure. The cutting element 100 includes a supporting substrate 104, and a cutting table 102 bonded to the supporting substrate 104 at an interface 106. The cutting table 102 may be disposed directly on the supporting substrate 104, and may exhibit at least one lateral side surface 108 (also referred to as the “barrel” of the cutting table 102), a cutting face 110 (also referred to as the “top” of the cutting table 102) opposite the interface 106 between the supporting substrate 104 and the cutting table 102, and at least one cutting edge 112 at a periphery (e.g., outermost boundary) of the cutting face 110.

The cutting table 102 and the supporting substrate 104 may each individually exhibit a generally cylindrical column shape, and the interface 106 between the supporting substrate 104 and cutting table 102 may be substantially planar. A ratio of a height of the cutting element 100 to an outer diameter of the cutting element 100 may be within a range of from about 0.1 to about 50, and a height (e.g., thickness)

of the cutting table 102 may be within a range of from about 0.3 millimeters (mm) to about 5 mm. Surfaces (e.g., the lateral side surface 108, the cutting face 110) of the cutting table 102 adjacent the cutting edge 112 may each be substantially planar, or one or more of the surfaces of the cutting table 102 adjacent the cutting edge 112 may be at least partially non-planar. Each of the surfaces of the cutting table 102 may be polished, or one or more of the surfaces of the cutting table 102 may be at least partially non-polished (e.g., lapped, but not polished). In addition, the cutting edge 112 of the cutting table 102 may be at least partially (e.g., substantially) chamfered (e.g., beveled), may be at least partially (e.g., substantially) radiused (e.g., arcuate), may be partially chamfered and partially radiused, or may be non-chamfered and non-radiused. As shown in FIG. 1, in some embodiments, the cutting edge 112 is chamfered. If the cutting edge 112 is at least partially chamfered, the cutting edge 112 may include a single (e.g., only one) chamfer, or may include multiple (e.g., more than one) chamfers (e.g., greater than or equal to two (2) chamfers, such as from two (2) chamfers to 1000 chamfers). If present, each of the chamfers may individually exhibit a width less than or equal to about 0.1 inch, such as within a range of from about 0.001 inch to about 0.1 inch.

FIG. 2 is an enlarged view illustrating how a microstructure of the cutting table 102 shown in FIG. 1 may appear under magnification. The cutting table 102 includes interspersed and inter-bonded diamond particles 114 (e.g., inter-bonded diamond particles) that form a three-dimensional (3D) network of polycrystalline diamond (PCD) material. The inter-bonded diamond particles 114 may have a multimodal particle size distribution. For example, as depicted in FIG. 2, the cutting table 102 may include larger diamond particles 114A (e.g., larger diamond particles) and smaller diamond particles 114B (e.g., smaller diamond particles). In additional embodiments, the inter-bonded diamond particles 114 may have a mono-modal particle size distribution (e.g., the smaller diamond particles 114B may be omitted, or the larger diamond particles 114A may be omitted). Direct inter-granular bonds between the larger diamond particles 114A and the smaller diamond particles 114B are represented in FIG. 2 by dashed lines 116. The larger diamond particles 114A may be monodisperse, wherein all the larger diamond particles 114A exhibit substantially the same size, or may be polydisperse, wherein the larger diamond particles 114A exhibit a range of sizes and are averaged. In addition, the smaller diamond particles 114B may be monodisperse, wherein all the smaller diamond particles 114B exhibit substantially the same size, or may be polydisperse, wherein the smaller diamond particles 114B exhibit a range of sizes and are averaged.

As shown in FIG. 2, interstitial spaces are present between the inter-bonded diamond particles 114 of the cutting table 102. The interstitial spaces are at least partially (e.g., substantially) filled with a thermally stable material 118 including at least one carbide precipitate (e.g., E<sub>21</sub>-type phase carbide precipitate, tetragonal P4/mm phase carbide precipitate) that is both thermally stable and mechanically stable. A standard enthalpy of formation of the carbide precipitate of the thermally stable material 118 is less than zero (indicating that the carbide precipitate is thermally stable), and an eigenvalue from a Young’s modulus calculation for the carbide precipitate of the thermally stable material 118 is positive (indicating that the carbide precipitate is mechanically stable). The thermally stable material 118 may render the cutting table 102 thermally stable without needing to leach the cutting table 102. For example,



the thermally stable material **118** may not significantly promote carbon transformations (e.g., graphite-to-diamond or vice versa) as compared to conventional cutting tables including inter-bonded diamond particles substantially exposed to conventional catalyst materials (e.g., catalytic cobalt, catalytic iron, catalytic nickel) within interstitial spaces between the inter-bonded diamond particles. Accordingly, the thermally stable material **118** may render the cutting table **102** more thermally stable than conventional cutting tables.

The carbide precipitate of the thermally stable material **118** may be a perovskite compound having the general chemical formula shown below:



wherein A comprises one or more of scandium (Sc), titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), yttrium (Y), zirconium (Zr), niobium (Nb), molybdenum (Mo), technetium (Tc), ruthenium (Ru), rhodium (Rh), palladium (Pd), silver (Ag), cadmium (Cd), hafnium (Hf), tantalum (Ta), tungsten (W), rhenium (Re), osmium (Os), iridium (Ir), platinum (Pt), gold (Au), mercury (Hg), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), actinium (Ac), thorium (Th), protoactinium (Pa), and uranium (U); X comprises one or more of aluminum (Al), gallium (Ga), tin (Sn), beryllium (Be), bismuth (Bi), tellurium (Te), antimony (Sb), selenium (Se), arsenic (As), germanium (Ge), silicon (Si), boron (B), and phosphorus (P); Z is carbon (C); and n is greater than or equal to 0 and less than or equal to 0.75 (i.e.,  $0 \leq n \leq 0.75$ ).

In some embodiments, the carbide precipitate of the thermally stable material **118** comprises an E2<sub>1</sub>-type phase carbide ( $\kappa$ -carbide) having formula (1) above. FIG. **21** shows a simplified perspective view of the lattice structure of a  $\kappa$ -carbide precipitate having formula (1) above. As shown in FIG. **21**, sites of "A" elements ("A sites") are at face centered ( $\frac{1}{2}$ ,  $\frac{1}{2}$ , 0) positions in the lattice structure of the  $\kappa$ -carbide precipitate; sites of "X" elements ("X sites") are at cube corner (0, 0, 0) positions in the lattice structure of the  $\kappa$ -carbide precipitate, and sites of "Z" elements or vacancies (i.e., vacancies corresponding to embodiments where  $0 < n \leq 0.75$  in formula (1) above) ("Z sites") are located at body centered ( $\frac{1}{2}$ ,  $\frac{1}{2}$ , 0) positions in the lattice structure of the  $\kappa$ -carbide precipitate.

In additional embodiments, the carbide precipitate of thermally stable material **118** comprises a non- $\kappa$ -carbide precipitate having formula (1) above. By way of non-limiting example, the carbide precipitate of the thermally stable material **118** may comprise a tetragonal P4/mmm phase carbide precipitate having formula (1) above, such as Co<sub>3</sub>GeC<sub>0.25</sub>. It was unexpectedly discovered that Co<sub>3</sub>GeC<sub>0.25</sub>, a tetragonal P4/mmm phase carbide precipitate, exhibits enhanced stability properties (e.g., thermal stability properties, mechanical stability properties) relative to Co<sub>3</sub>GeC, a  $\kappa$ -carbide precipitate. The thermally stable material **118** may include one or more non- $\kappa$ -carbide precipitates in addition to or in place of one or more  $\kappa$ -carbide precipitates.

The carbide precipitate (e.g.,  $\kappa$ -carbide precipitate, non- $\kappa$ -carbide precipitate) of the thermally stable material **118** includes at least three different elements. For example, the carbide precipitate may be a ternary (e.g., triple element) carbide precipitate (e.g., a ternary  $\kappa$ -carbide precipitate, a

ternary non- $\kappa$ -carbide precipitate) including a single (e.g., only one) first element (e.g., Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, or U) occupying all A sites in the lattice structure of the carbide precipitate; a single second element (e.g., Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, or P) occupying all X sites in the lattice structure of the carbide precipitate; and a single third element (e.g., C) occupying at least some (e.g., all, less than all) Z sites in the lattice structure of the carbide precipitate. In additional embodiments, the carbide precipitate of the thermally stable material **118** includes more than three different elements (e.g., at least four different elements). By way of non-limiting example, the carbide precipitate of the thermally stable material **118** may comprise a quaternary (e.g., quadruple element) carbide precipitate (e.g., a quaternary  $\kappa$ -carbide precipitate, a quaternary non- $\kappa$ -carbide precipitate). The quaternary carbide precipitate may, for example, include a single (e.g., only one) first element (e.g., one of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U) occupying A sites in the lattice structure of the carbide precipitate, two different second elements (e.g., two of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P) occupying X sites in the lattice structure of the carbide precipitate, and a single third element (e.g., C) occupying at least some (e.g., all, less than all) Z sites in the lattice structure of the carbide precipitate; or may include two different first elements (e.g., two of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U) occupying A sites in the lattice structure of the carbide precipitate, a single (e.g., only one) second element (e.g., one of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P) occupying X sites in the lattice structure of the carbide precipitate, and a single element (e.g., C) occupying at least some (e.g., all, less than all) Z sites in the lattice structure of the carbide precipitate. C may render carbide precipitates of the thermally stable material **118** stable at ambient pressure and temperature conditions.

By way of non-limiting example, the thermally stable material **118** may include one or more ternary carbide precipitates (e.g., ternary  $\kappa$ -carbide precipitates, ternary non- $\kappa$ -carbide precipitates) selected from Sm<sub>3</sub>SnC<sub>1-n</sub>, Sm<sub>3</sub>BiC<sub>1-n</sub>, Sm<sub>3</sub>TeC<sub>1-n</sub>, Sm<sub>3</sub>PC<sub>1-n</sub>, Sm<sub>3</sub>SiC<sub>1-n</sub>, Sm<sub>3</sub>GaC<sub>1-n</sub>, Sc<sub>3</sub>SnC<sub>1-n</sub>, Sc<sub>3</sub>GeC<sub>1-n</sub>, Sc<sub>3</sub>SbC<sub>1-n</sub>, Sc<sub>3</sub>AsC<sub>1-n</sub>, Sm<sub>3</sub>BeC<sub>1-n</sub>, Sc<sub>3</sub>PC<sub>1-n</sub>, Sc<sub>3</sub>SiC<sub>1-n</sub>, Y<sub>3</sub>SnC<sub>1-n</sub>, Sc<sub>3</sub>BiC<sub>1-n</sub>, Tm<sub>3</sub>SnC<sub>1-n</sub>, Er<sub>3</sub>SnC<sub>1-n</sub>, Sc<sub>3</sub>TeC<sub>1-n</sub>, Y<sub>3</sub>SbC<sub>1-n</sub>, Sc<sub>3</sub>SeC<sub>1-n</sub>, Ho<sub>3</sub>SnC<sub>1-n</sub>, Sc<sub>3</sub>GaC<sub>1-n</sub>, Dy<sub>3</sub>SnC<sub>1-n</sub>, Y<sub>3</sub>BiC<sub>1-n</sub>, Tb<sub>3</sub>SnC<sub>1-n</sub>, Tm<sub>3</sub>SbC<sub>1-n</sub>, Er<sub>3</sub>SbC<sub>1-n</sub>, Lu<sub>3</sub>SbC<sub>1-n</sub>, Lu<sub>3</sub>GeC<sub>1-n</sub>, Ti<sub>3</sub>GaC<sub>1-n</sub>, Ti<sub>3</sub>GeC<sub>1-n</sub>, Gd<sub>3</sub>SnC<sub>1-n</sub>, Tb<sub>3</sub>SbC<sub>1-n</sub>, Y<sub>3</sub>GeC<sub>1-n</sub>, Er<sub>3</sub>BiC<sub>1-n</sub>, Ho<sub>3</sub>BiC<sub>1-n</sub>, Tm<sub>3</sub>BiC<sub>1-n</sub>, Lu<sub>3</sub>AsC<sub>1-n</sub>, Tm<sub>3</sub>GeC<sub>1-n</sub>, Dy<sub>3</sub>BiC<sub>1-n</sub>, Lu<sub>3</sub>BiC<sub>1-n</sub>, Tm<sub>3</sub>AsC<sub>1-n</sub>, Tb<sub>3</sub>BiC<sub>1-n</sub>, Ti<sub>3</sub>SnC<sub>1-n</sub>, Er<sub>3</sub>AsC<sub>1-n</sub>, Ti<sub>3</sub>SiC<sub>1-n</sub>, Y<sub>3</sub>TeC<sub>1-n</sub>, Gd<sub>3</sub>BiC<sub>1-n</sub>, Ce<sub>3</sub>TeC<sub>1-n</sub>, Ti<sub>3</sub>AlC<sub>1-n</sub>, Zr<sub>3</sub>SnC<sub>1-n</sub>, Dy<sub>3</sub>AsC<sub>1-n</sub>, La<sub>3</sub>BiC<sub>1-n</sub>, Sc<sub>3</sub>AlC<sub>1-n</sub>, Yb<sub>3</sub>SeC<sub>1-n</sub>, Tb<sub>3</sub>AsC<sub>1-n</sub>, Lu<sub>3</sub>PC<sub>1-n</sub>, Yb<sub>3</sub>TeC<sub>1-n</sub>, Lu<sub>3</sub>SnC<sub>1-n</sub>, Eu<sub>3</sub>SeC<sub>1-n</sub>, Er<sub>3</sub>TeC<sub>1-n</sub>, Ti<sub>3</sub>SbC<sub>1-n</sub>, Lu<sub>3</sub>SiC<sub>1-n</sub>, Tm<sub>3</sub>TeC<sub>1-n</sub>, Tm<sub>3</sub>PC<sub>1-n</sub>, Gd<sub>3</sub>TeC<sub>1-n</sub>, Gd<sub>3</sub>AsC<sub>1-n</sub>, Zr<sub>3</sub>SbC<sub>1-n</sub>, Lu<sub>3</sub>GaC<sub>1-n</sub>, Er<sub>3</sub>PC<sub>1-n</sub>, Sm<sub>3</sub>BC<sub>1-n</sub>, Lu<sub>3</sub>TeC<sub>1-n</sub>, Ho<sub>3</sub>PC<sub>1-n</sub>, Tm<sub>3</sub>SiC<sub>1-n</sub>, Er<sub>3</sub>SiC<sub>1-n</sub>, Dy<sub>3</sub>PC<sub>1-n</sub>, Tm<sub>3</sub>GaC<sub>1-n</sub>, Ce<sub>3</sub>AsC<sub>1-n</sub>, Y<sub>3</sub>GaC<sub>1-n</sub>, Ho<sub>3</sub>SiC<sub>1-n</sub>, Tb<sub>3</sub>PC<sub>1-n</sub>, Er<sub>3</sub>GaC<sub>1-n</sub>, Dy<sub>3</sub>SiC<sub>1-n</sub>, Eu<sub>3</sub>BiC<sub>1-n</sub>, Hf<sub>3</sub>GaC<sub>1-n</sub>, Ho<sub>3</sub>GaC<sub>1-n</sub>, Gd<sub>3</sub>PC<sub>1-n</sub>, Gd<sub>3</sub>SeC<sub>1-n</sub>, Lu<sub>3</sub>AlC<sub>1-n</sub>, Ce<sub>3</sub>SnC<sub>1-n</sub>, Tb<sub>3</sub>SiC<sub>1-n</sub>, Hf<sub>3</sub>SnC<sub>1-n</sub>, Dy<sub>3</sub>GaC<sub>1-n</sub>, Tm<sub>3</sub>AlC<sub>1-n</sub>, Gd<sub>3</sub>SiC<sub>1-n</sub>, Ti<sub>3</sub>BiC<sub>1-n</sub>, Tb<sub>3</sub>GaC<sub>1-n</sub>, Er<sub>3</sub>AlC<sub>1-n</sub>, Yb<sub>3</sub>BiC<sub>1-n</sub>, Yb<sub>3</sub>SbC<sub>1-n</sub>, La<sub>3</sub>PC<sub>1-n</sub>,



Eu<sub>3</sub>AsC<sub>1-n</sub>, Fe<sub>3</sub>AlC<sub>1-n</sub>, Ho<sub>3</sub>AlC<sub>1-n</sub>, Gd<sub>3</sub>GaC<sub>1-n</sub>, Yb<sub>3</sub>ASC<sub>1-n</sub>,  
 Th<sub>3</sub>BiC<sub>1-n</sub>, Ac<sub>3</sub>SbC<sub>1-n</sub>, Th<sub>3</sub>SnC<sub>1-n</sub>, Tb<sub>3</sub>AlC<sub>1-n</sub>, Eu<sub>3</sub>PC<sub>1-n</sub>,  
 Fe<sub>3</sub>SiC<sub>1-n</sub>, Ti<sub>3</sub>BeC<sub>1-n</sub>, Yb<sub>3</sub>PC<sub>1-n</sub>, Gd<sub>3</sub>AlC<sub>1-n</sub>, Hf<sub>3</sub>PC<sub>1-n</sub>,  
 V<sub>3</sub>SiC<sub>1-n</sub>, Ce<sub>3</sub>SiC<sub>1-n</sub>, V<sub>3</sub>GeC<sub>1-n</sub>, Fe<sub>3</sub>GaC<sub>1-n</sub>, Rh<sub>3</sub>AlC<sub>1-n</sub>,  
 Th<sub>3</sub>GeC<sub>1-n</sub>, V<sub>3</sub>AlC<sub>1-n</sub>, Fe<sub>3</sub>GeC<sub>1-n</sub>, V<sub>3</sub>GaC<sub>1-n</sub>, Th<sub>3</sub>PC<sub>1-n</sub>,  
 V<sub>3</sub>PC<sub>1-n</sub>, V<sub>3</sub>SnC<sub>1-n</sub>, Fe<sub>3</sub>SnC<sub>1-n</sub>, Zr<sub>3</sub>BeC<sub>1-n</sub>, Hf<sub>3</sub>BeC<sub>1-n</sub>,  
 Nb<sub>3</sub>GaC<sub>1-n</sub>, Sc<sub>3</sub>BeC<sub>1-n</sub>, Th<sub>3</sub>AlC<sub>1-n</sub>, V<sub>3</sub>SbC<sub>1-n</sub>, Ce<sub>3</sub>AlC<sub>1-n</sub>,  
 Co<sub>3</sub>AlC<sub>1-n</sub>, V<sub>3</sub>AsC<sub>1-n</sub>, Ni<sub>3</sub>AlC<sub>1-n</sub>, Co<sub>3</sub>GaC<sub>1-n</sub>, Ti<sub>3</sub>BC<sub>1-n</sub>,  
 Rh<sub>3</sub>GaC<sub>1-n</sub>, Fe<sub>3</sub>BeC<sub>1-n</sub>, Fe<sub>3</sub>SbC<sub>1-n</sub>, Sc<sub>3</sub>BC<sub>1-n</sub>, U<sub>3</sub>PC<sub>1-n</sub>,  
 Fe<sub>3</sub>PC<sub>1-n</sub>, Co<sub>3</sub>SiC<sub>1-n</sub>, Hf<sub>3</sub>BiC<sub>1-n</sub>, V<sub>3</sub>BeC<sub>1-n</sub>, V<sub>3</sub>TeC<sub>1-n</sub>,  
 Ni<sub>3</sub>GaC<sub>1-n</sub>, Lu<sub>3</sub>BeC<sub>1-n</sub>, Mn<sub>3</sub>AlC<sub>1-n</sub>, Ru<sub>3</sub>AlC<sub>1-n</sub>, Fe<sub>3</sub>AsC<sub>1-n</sub>,  
 Ta<sub>3</sub>SnC<sub>1-n</sub>, Mn<sub>3</sub>SiC<sub>1-n</sub>, V<sub>3</sub>SeC<sub>1-n</sub>, U<sub>3</sub>SeC<sub>1-n</sub>, Co<sub>3</sub>SnC<sub>1-n</sub>,  
 Co<sub>3</sub>BeC<sub>1-n</sub>, Co<sub>3</sub>GeC<sub>1-n</sub>, U<sub>3</sub>SiC<sub>1-n</sub>, Cr<sub>3</sub>SiC<sub>1-n</sub>, V<sub>3</sub>BiC<sub>1-n</sub>,  
 Tc<sub>3</sub>AlC<sub>1-n</sub>, La<sub>3</sub>SiC<sub>1-n</sub>, Rh<sub>3</sub>SnC<sub>1-n</sub>, Cr<sub>3</sub>AlC<sub>1-n</sub>, U<sub>3</sub>AsC<sub>1-n</sub>,  
 Mn<sub>3</sub>GaC<sub>1-n</sub>, Th<sub>3</sub>SiC<sub>1-n</sub>, Rh<sub>3</sub>BeC<sub>1-n</sub>, Ni<sub>3</sub>BeC<sub>1-n</sub>, Mn<sub>3</sub>GeC<sub>1-n</sub>,  
 Cr<sub>3</sub>GeC<sub>1-n</sub>, Pd<sub>3</sub>AlC<sub>1-n</sub>, and Cr<sub>3</sub>GaC<sub>1-n</sub>, wherein  $0 \leq n \leq 0.75$ .

In some embodiments, the thermally stable material **118** includes one or more carbide precipitates (e.g., ternary  $\kappa$ -carbide precipitates, ternary non- $\kappa$ -carbide precipitates, quaternary  $\kappa$ -carbide precipitates, and/or quaternary non- $\kappa$ -carbide precipitates) free of (i.e., not including) Co. All of the carbide precipitates of the thermally stable material **118** may be free of Co, or less than all of the carbide precipitates of the thermally stable material **118** may be free of Co. In additional embodiments, the thermally stable material **118** includes one or more carbide precipitates (e.g., ternary  $\kappa$ -carbide precipitates, ternary non- $\kappa$ -carbide precipitates, quaternary  $\kappa$ -carbide precipitates, and/or quaternary non- $\kappa$ -carbide precipitates) free of (i.e., not including) Ni. All of the carbide precipitates of the thermally stable material **118** may be free of Ni, or less than all of the carbide precipitates of the thermally stable material **118** may be free of Ni. In further embodiments, the thermally stable material **118** includes one or more carbide precipitates (e.g., ternary  $\kappa$ -carbide precipitates, ternary non- $\kappa$ -carbide precipitates, quaternary  $\kappa$ -carbide precipitates, and/or quaternary non- $\kappa$ -carbide precipitates) free of (i.e., not including) Fe. All of the carbide precipitates of the thermally stable material **118** may be free of Fe, or less than all of the carbide precipitates of the thermally stable material **118** may be free of Fe. In still further embodiments, all of carbide precipitates of the thermally stable material **118** are free of (i.e., do not include) Co, Fe, and Ni.

In addition to carbide precipitates (e.g.,  $\kappa$ -carbide precipitates, non- $\kappa$ -carbide precipitates) having formula (1) above, the thermally stable material **118** of the cutting table **102** may include one or more intermetallic compound phase precipitates. As a non-limiting example, the thermally stable material **118** may include one or more of FCC L1<sub>2</sub> phase (e.g., gamma prime ( $\gamma'$ ) phase) precipitates, FCC DO<sub>22</sub> phase precipitates, D8<sub>5</sub> phase precipitates, DO<sub>19</sub> phase precipitates, and BCC/B2 phase precipitates. In some embodiments, the thermally stable material **118** of the cutting table **102** is formed of and includes carbide precipitate(s) having formula (1) above and FCC L1<sub>2</sub> phase precipitates. The thermally stable material **118** of the cutting table **102** may also include other precipitates formed of and including elements of the carbide precipitates having formula (1) above. By way of non-limiting example, the thermally stable material **118** may include, other beta ( $\beta$ ) phase precipitates (e.g.,  $\beta$  phase precipitates not having B2 ordering on a BCC parent crystal structure), FCC L1<sub>0</sub> phase (e.g., gamma ( $\gamma$ ) phase) precipitates, and/or other carbide precipitates not having formula (1) above (e.g., WC precipitates; M<sub>x</sub>C precipitates, where  $x > 2$  and M comprises one or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh,

Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U).

As shown in FIG. **2**, the thermally stable material **118** may at least partially (e.g., substantially) coat (e.g., cover) surfaces of the inter-bonded diamond particles **114** of the cutting table **102**. The thermally stable material **118** may be located directly on the surfaces of the inter-bonded diamond particles **114** of the cutting table **102**, and may at least partially impede (e.g., substantially prevent) back-conversion of the inter-bonded diamond particles **114** to other forms or phases of carbon (e.g., graphitic carbon, amorphous carbon, etc.). In some embodiments, substantially all catalytic elements adjacent the inter-bonded diamond particles **114** of the cutting table **102** are partitioned (e.g., incorporated) into carbide precipitates (e.g.,  $\kappa$ -carbide precipitates, non- $\kappa$ -carbide precipitates) having formula (1) above and/or other precipitates (e.g., FCC L1<sub>2</sub> phase precipitates; FCC DO<sub>22</sub> phase precipitates; D8<sub>5</sub> phase precipitates; DO<sub>19</sub> phase precipitates; BCC/B2 phase precipitates; other R phase precipitates; FCC L1<sub>0</sub> phase precipitates; other carbide precipitates not having formula (1) above). Accordingly, otherwise catalytic elements of the thermally stable material **118** may not catalyze reactions that decompose the inter-bonded diamond particles **114** during normal use and operation of the cutting table **102**. In additional embodiments, one or more unreacted catalytic elements may be present within the thermally stable material **118**. However, the particle sizes and distributions of the carbide precipitates having formula (1) above and/or other precipitates may be controlled to limit the exposure of the inter-bonded diamond particles **114** of the cutting table **102** to such unreacted catalytic elements.

The cutting table **102** may exhibit enhanced abrasion resistance and thermal stability up to a melting temperature or theoretical diamond stability temperature, at or near atmospheric conditions, whichever is lower, of the thermally stable material **118**. For example, if the melting temperature of the thermally stable material **118** is about 1,200° C., the cutting table **102** may be thermally and physically stable at temperatures within a range from about 1,000° C. to about 1,100° C., which corresponds to the theoretical limit of diamond stability under or near atmospheric conditions (assuming no oxidation occurs). The thermally stable material **118** within interstitial spaces between the inter-bonded diamond particles **114** of the cutting table **102** may be thermodynamically stable at ambient pressure and temperatures, as well as at temperatures and pressures experienced, for example, during downhole drilling. The thermally stable material **118** may render the cutting table **102** thermally stable without having to remove (e.g., leach) material from the interstitial spaces of the cutting table **102**.

With returned reference to FIG. **1**, the material composition of the supporting substrate **104** may at least partially depend on the methodology (e.g., process) employed to form the cutting table **102** of the cutting element **100**. For example, in some embodiments, the supporting substrate **104** includes tungsten carbide (WC) particles dispersed within a homogenized binder formed of and including elements of the thermally stable material **118** (FIG. **2**) of the cutting table **102**. The homogenized binder may, for example, comprise a substantially homogeneous alloy (e.g., a substantially homogeneous peritectic alloy) of the elements included in the thermally stable material **118** (e.g., the elements included in the carbide precipitate(s) of the thermally stable material **118** having formula (1) above) of the cutting table **102**. The homogenized binder of the supporting substrate **104** may be employed (e.g., diffused from the



supporting substrate **104** into a diamond-containing material adjacent the supporting substrate **104**) to form the cutting table **102** (including the thermally stable material **118** (FIG. 2) thereof) during the formation of the cutting element **100**, as described in further detail below with reference to FIGS. 3A and 3B. In additional embodiments, the supporting substrate **104** may have a different material composition, such as a material composition free of one or more of the elements present in the thermally stable material **118** of the cutting table **102** (e.g., free of one or more of the elements included in the carbide precipitate(s) of the thermally stable material **118** having formula (1) above). In such embodiments, such omitted elements may be obtained from one or more different sources (e.g., one or more sources other than the supporting substrate **104**) during the formation of the cutting table **102** (including the thermally stable material **118** (FIG. 2) thereof) and the cutting element **100**. For example, one or more of the elements included in the thermally stable material **118** (FIG. 2) (e.g., one or more of the elements included in the carbide precipitate(s) of the thermally stable material **118** having formula (1) above) of the cutting table **102** may be obtained from discrete alloy particles included in a diamond-containing material adjacent the supporting substrate **104** during the formation of the cutting element **100**, as described in further detail below with reference to FIGS. 4A and 4B. As another example, one or more of the elements included in the thermally stable material **118** (FIG. 2) (e.g., one or more of the elements included in the carbide precipitate(s) of the thermally stable material **118** having formula (1) above) of the cutting table **102** may be obtained from additional structures (e.g., foils, plates, shims, meshes, films, layers) provided adjacent at least a diamond-containing material employed to form the cutting table **102** during the formation of the cutting element **100**, as described in further detail below with reference to FIGS. 5A and 5B.

An embodiment of a method of forming the cutting element **100** will now be described with reference to FIGS. 3A and 3B, which illustrate simplified cross-sectional views of a container **300** in a process of forming the cutting element **100** shown in FIG. 1. With the description provided below, it will be readily apparent to one of ordinary skill in the art that the methods described herein may be used in various devices. In other words, the methods of the disclosure may be used whenever it is desired to form a thermally stable structure, such as a thermally stable cutting table (e.g., a thermally stable diamond table, such as a thermally stable PDC), for an earth-boring tool.

Referring to FIG. 3A, a diamond-containing material **301** may be provided within the container **300**, and a supporting substrate **304** may be provided directly on the diamond-containing material **301**. The container **300** may substantially surround and hold the diamond-containing material **301** and the supporting substrate **304**. As shown in FIG. 3A, the container **300** may include an inner cup **308** in which the diamond-containing material **301** and a portion of the supporting substrate **304** may be disposed, a bottom end piece **306** in which the inner cup **308** may be at least partially disposed, and a top end piece **310** surrounding the supporting substrate **304** and coupled (e.g., swage bonded) to one or more of the inner cup **308** and the bottom end piece **306**. In additional embodiments, the bottom end piece **306** may be omitted (e.g., absent).

The diamond-containing material **301** (e.g., diamond powder) may be formed of and include discrete diamond particles (e.g., discrete natural diamond particles, discrete synthetic diamond particles, combinations thereof, etc.). The

discrete diamond particles may individually exhibit a desired particle size. The discrete diamond particles may comprise, for example, one or more of micro-sized diamond particles and nano-sized diamond particles. In addition, each of the discrete diamond particles may individually exhibit a desired shape, such as at least one of a spherical shape, a hexahedral shape, an ellipsoidal shape, a cylindrical shape, a conical shape, or an irregular shape. In some embodiments, each of the discrete diamond particles of the diamond-containing material **301** exhibits a substantially spherical shape. The discrete diamond particles may be monodisperse, wherein each of the discrete diamond particles exhibits substantially the same material composition, size, and shape, or may be polydisperse, wherein at least one of the discrete diamond particles exhibits one or more of a different material composition, a different particle size, and a different shape than at least one other of the discrete diamond particles. The diamond-containing material **301** may be formed by conventional processes, which are not described herein.

The supporting substrate **304** comprises a consolidated structure including WC particles dispersed within a homogenized binder (e.g., a substantially homogeneous alloy, such as a substantially homogeneous peritectic alloy) comprising at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U; at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P; C; and W. The homogenized binder may, for example, comprise from about 35 weight percent (wt %) to about 95 wt % of the first element; from about 2.0 wt % to about 60 wt % of the second element; from about 0.1 wt % C to about 10 wt % C; and a remainder of W. In some embodiments, the homogenized binder is substantially free of Co. In additional embodiments, the homogenized binder is substantially free of Ni. In further embodiments, the homogenized binder is substantially free of Fe. In still further embodiments, the homogenized binder is substantially free of each of Co, Ni, and Fe. The supporting substrate **304** may include from about 80 wt % to about 95 wt % of the WC particles, and from about 5 wt % to about 20 wt % of the homogenized binder. In some embodiments, the supporting substrate **304** includes about 88 wt % WC particles, and about 12 wt % of a homogenized binder comprising the first element (e.g., one or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U), the second element (e.g., one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P); C; and W. The homogenized binder of the supporting substrate **304** may have a liquidus temperature greater than or equal to about 750° C., such as within a range of from about 750° C. to about 1500° C., or from about 1000° C. to about 1500° C. As described in further detail below, the homogenized binder of the supporting substrate **304** may be employed to convert the discrete diamond particles of the diamond-containing material **301** into inter-bonded diamond particles.

As described in further detail below, the supporting substrate **304** may be formed through a multi-step process that includes forming a precursor composition, and then consolidating the precursor composition. With the description as provided below, it will be readily apparent to one of ordinary skill in the art that the methods described herein in relation to the formation of the supporting substrate **304** may be used in various applications. The methods described herein may



be used whenever it is desired to form a consolidated structure including particles of a hard material (e.g., WC particles) dispersed in a homogenized binder.

The process of forming a precursor composition includes combining (e.g., mixing) a preliminary powder with a WC powder, a binding agent, and, optionally, one or more additive(s) to form a precursor composition. The preliminary powder may include at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U, at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P, and at least one third element selected from C and W. In some embodiments, the preliminary powder is substantially free of Co. In additional embodiments, the preliminary powder is substantially free of Ni. In further embodiments, the preliminary powder is substantially free of Fe. In still further embodiments, the preliminary powder is substantially free of each of Co, Ni, and Fe. The preliminary powder may, for example, comprise discrete alloy particles each individually including the first element, the second element, and the third element; and/or may comprise discrete elemental (e.g., non-alloy) particles (e.g., discrete elemental particles of the first element, discrete elemental particles of the second element, and/or discrete elemental particles of third element). During the process of forming the precursor composition, the discrete particles (e.g., discrete alloy particles and/or discrete elemental particles) of the preliminary powder may be distributed relative to the discrete WC particles of the WC powder and the additive(s) (if any) so as to facilitate the formation of a consolidated structure (e.g., a supporting substrate) able to effectuate the formation of a cutting element including a thermally stable cutting table (e.g., a thermally stable PDC table), as described in further detail below.

The preliminary powder may include any amounts of the first element (e.g., one or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U), the second element (e.g., one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P), and the third element (e.g., one or more of C and W) able to facilitate the formation of a consolidated structure formed of and including WC particles and a homogenized binder including desired amounts of the first element, the second element, C, and W through the subsequent consolidation process. Accordingly, amounts of one or more of the first element, the second element, and the third element in the preliminary powder (e.g., as effectuated by the formulations and relative amounts of the discrete alloy particles and/or the discrete elemental particles thereof) may be selected at least partially based on amounts of W and C in the WC powder (e.g., as effectuated by the formulations and relative amounts of the discrete WC particles thereof) facilitating the formation of the homogenized binder of the consolidated structure. In turn, as described in further detail below, a material composition of the homogenized binder may be selected at least partially based on desired melting properties of the homogenized binder, on desired catalytic properties of the homogenized binder for the formation of a compact structure (e.g., a cutting table, such as a PDC table) including inter-bonded diamond particles, and on desired stability properties (e.g., thermal stability properties, mechanical stability properties) of the compact structure effectuated by the formation of a thermally stable material (e.g., the thermally stable material **118**

previously described with reference to FIG. 2) from portions of the homogenized binder remaining within interstitial spaces between the inter-bonded diamond particles (e.g., the inter-bonded diamond particles **114** of the cutting table **102** previously described with reference to FIG. 2) following the formation thereof.

In some embodiments, the preliminary powder includes from about 60 wt % to about 98.75 wt % of the first element (e.g., one or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U), from about 2 wt % to about 40 wt % of the second element (e.g., one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P); and from about 0.25 wt % to about 2.0 wt % of the third element (e.g., one or more of W and C). Relatively higher concentrations of the second element may enhance the suppression of undesirable reactions (e.g., binary carbide forming reactions) between the first element and C during the formation of a compact structure (e.g., a cutting table, such as a PDC table) using a liquid phase of a homogenized binder subsequently formed from the precursor composition, enhancing the catalytic properties (e.g., carbon solubility and liquid phase transport) of the first element for the formation of inter-bonded diamond particles. By way of non-limiting example, if the first element comprises an element (e.g., Y, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W) that is highly reactive with C to form a binary carbide (e.g., YC, TiC, ZrC, HfC, VC, NbC, TaC, CrC, MoC, WC), the second element may suppress reactions between the first element and C that would otherwise form the binary carbide so as to permit the first element to act as a catalyst for the formation of inter-bonded diamond particles during a sintering process at or above the liquidus temperature of the homogenized binder. Relatively higher concentrations of the second element may also enhance thermal stability properties of a compact structure (e.g., a cutting table, such as a PDC table) formed using the liquid phase of the homogenized binder, but may also increase and/or widen the melting temperature range of the homogenized binder as compared to homogenized binders having relatively lower concentrations of the second element. Even if the first element comprises an element (e.g., Co, Ni, Ag, Cu, Au, Pt, Tc) that is not highly reactive with C to form a binary carbide, the second element may enhance the stability properties (e.g., thermal stability properties, mechanical stability properties) of the compact structure (e.g., a cutting table, such as a PDC table) by facilitating the formation of carbide precipitates (e.g.,  $\kappa$ -carbide precipitates, non- $\kappa$ -carbide precipitates) having formula (1) above through the sintering process. In addition, relatively higher concentrations of C in the preliminary powder may enhance thermal stability properties of the compact structure formed using the liquid phase of homogenized binder through the formation of carbide precipitates, but may also modify (e.g., suppress) the melting characteristics of the homogenized binder by modifying the melting and solidification paths toward monovariant and invariant reaction lines.

If the preliminary powder includes two or more of the second elements (e.g., two or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P), the preliminary powder may include substantially the same weight percentage of each of the two or more of the second elements; or may include a different weight percentage of at least one of the two or more of the second elements than at least one other of the two or more of the second elements. In addition, if the preliminary powder includes two or more of the first elements (e.g., two



or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U), the preliminary powder may include substantially the same weight percentage of each of the two or more of the first elements; or may include a different weight percentage of at least one of the two or more of the first elements than at least one other of the two or more of the first elements.

In some embodiments, the material composition of the preliminary powder is selected relative to the material composition of WC powder to facilitate the subsequent formation of a homogenized binder including amounts of the first element (e.g., one or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U), the second element (one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P), C, and W facilitating the formation of a compact structure (e.g., cutting table, PDC table) including inter-bonded diamond particles using a liquid phase of the homogenized binder. The amounts of at least the first element and the second element in the preliminary powder may, for example, be selected such that the second element minimizes (e.g., substantially limits) reactions (e.g., binary carbide forming reactions) between the first element and carbon of discrete diamond particles that may otherwise substantially preclude the first element from being able to catalyze the formation of inter-bonded diamond particles from the discrete diamond particles using a liquid phase of the homogenized binder. In some embodiments, amounts of the second element are selected relative to amounts of the first element such that substantially none of the first element reacts with C to form a binary carbide upon infiltration (e.g., diffusion) of a liquid phase of the homogenized binder into the diamond-containing material **301** during subsequent HTHP processing to convert the discrete diamond particles of the diamond-containing material **301** into inter-bonded diamond particles. Accordingly, substantially all of the first element included within the liquid phase of the homogenized binder may catalyze the formation of the inter-bonded diamond particles. Amounts of the first element, the second element, and the third element (e.g., one or more of W and C) in the preliminary powder may be selected to permit a melting temperature range of the homogenized binder to be within a temperature range suitable for thermally treating (e.g., sintering) the diamond-containing material **301** to form the compact structure. In some embodiments, the preliminary powder includes about 86 wt % of the first element, and about 13 wt % of the second element.

In additional embodiments, the material composition of the preliminary powder is selected relative to the material compositions of the WC powder to facilitate the subsequent formation of a homogenized binder having a relatively lower melting temperature range and/or relatively narrower melting temperature range than a homogenized binder formulated to minimize (e.g., substantially limit) reactions (e.g., binary carbide forming reactions) between the first element and carbon of discrete diamond particles that may otherwise substantially preclude the first element from being able to catalyze the formation of inter-bonded diamond particles from discrete diamond particles using a liquid phase of the homogenized binder. For example, amounts of the second element (e.g., one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P) of the preliminary powder may be selected relative to amounts of the first element (e.g., one or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo,

Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U) such that less than all of the first element is impeded (e.g., precluded) from reacting with C to form a binary carbide upon infiltration (e.g., diffusion) of a liquid phase of the homogenized binder into the diamond-containing material **301** during subsequent HTHP processing to convert the discrete diamond particles of the diamond-containing material **301** into inter-bonded diamond particles. A majority (e.g., greater than or equal to 70 percent but less than 100 percent, greater than or equal to 80 percent but less than 100 percent, greater than or equal to 90 percent but less than 100 percent, greater than or equal to 95 percent but less than 100 percent) of the first element may catalyze the formation of the inter-bonded diamond particles, but at least a portion of the first element may react with C to form a binary carbide upon infiltration of the liquid phase of the homogenized binder into the diamond-containing material **301**. Accordingly, a compact structure (e.g., cutting table, PDC table) formed using the liquid phase of the homogenized binder may include binary carbides within interstitial spaces between inter-bonded diamond particles thereof. In some embodiments, the preliminary powder includes about 89 wt % Co; about 9.2 wt % of one or more of Al, Ga, Sn, Be, Ge, and Si; and about 0.8 wt % C.

In some embodiments, at least some (e.g., all) of the discrete particles of the preliminary powder comprise discrete alloy particles individually formed of and including an alloy including at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U, at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P, and at least one third element selected from C and W. Each of the discrete alloy particles may include substantially the same elements and element ratios of as each other of the discrete alloy particles, or one or more of the discrete alloy particles may include different elements and/or different element ratios than one or more other of the discrete alloy particles, so long as the preliminary powder as a whole includes desired and predetermined ratios of the first element, the second element, and the third element. In some embodiments, the preliminary powder is formed of and includes discrete alloy particles having substantially the same amounts of one or more of the first element, the second element, and the third element as one another. In additional embodiments, the preliminary powder is formed of and includes discrete alloy particles having different amounts of the first element, the second element, and/or the third element than one another.

If included in the preliminary powder, the discrete alloy particles may be formed by conventional processes (e.g., ball milling processes, attritor milling processes, cryomilling processes, jet milling processes, powder atomization processes, etc.), which are not described herein. As a non-limiting example, an initial powder formed of and including particles of the first element (e.g., one or more of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U), the second element (e.g., one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P), and the third element (e.g., one or more of C and W), alloys thereof, and/or combinations thereof may be provided into an attritor mill containing mixing structures (e.g., mixing spheres, mixing bars, etc.), and may then be subjected to a mechanical alloying process until the discrete alloy particles are formed. During the



mechanical alloying process collisions between the mixing structures and the initial powder may cause particles of different materials to fracture and/or be welded or smeared together. Relatively larger particles may fracture during the mechanical welding process and relatively smaller particles may weld together, eventually forming discrete alloy particles each individually comprising a substantially homogeneous mixture of the constituents of the initial powder in substantially the same proportions of the initial powder. As another non-limiting example, an alloy material may be formed by conventional melting and mixing processes, and then the alloy material may be formed into the discrete alloy particles by one or more conventional atomization processes.

In additional embodiments, at least some (e.g., all) of the discrete particles of the preliminary powder comprise discrete elemental particles, such as first discrete elemental particles individually formed a single (e.g., only one) first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U; second discrete elemental particles individually formed of a single (e.g., only one) second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P; and/or third discrete elemental particles individually formed of a single (e.g., only one) element selected from C (e.g., discrete graphite particles, discrete graphene particles, discrete fullerene particles, discrete carbon nanofibers, discrete carbon nanotubes, etc.) and W. The preliminary powder may include any amounts of the discrete elemental particles permitting the preliminary powder as a whole to include desired and predetermined ratios of one or more of the first element, the second element, and the third element. If included in the preliminary powder, the discrete elemental particles may be formed by conventional processes (e.g., conventional milling processes), which are not described herein.

The preliminary powder may include discrete alloy particles but may be substantially free of discrete elemental particles; may include discrete elemental particles but may be substantially free of discrete alloy particles; or may include a combination of discrete alloy particles and discrete elemental particles. In some embodiments, the preliminary powder only includes discrete alloy particles. In additional embodiments, the preliminary powder only includes discrete elemental particles. In further embodiments, the preliminary powder includes a combination of discrete alloy particles and discrete elemental particles.

Each of the discrete particles (e.g., discrete alloy particles and/or discrete elemental particles) of the preliminary powder may individually exhibit a desired particle size, such as a particle size less than or equal to about 1000 micrometers ( $\mu\text{m}$ ). The discrete particles may comprise, for example, one or more of discrete micro-sized particles and discrete nano-sized particles. As used herein, the term "micro-sized" means and includes a particle size with a range of from about one (1)  $\mu\text{m}$  to about 1000  $\mu\text{m}$ , such as from about 1  $\mu\text{m}$  to about 500  $\mu\text{m}$ , from about 1  $\mu\text{m}$  to about 100  $\mu\text{m}$ , or from about 1  $\mu\text{m}$  to about 50  $\mu\text{m}$ . As used herein, the term "nano-sized" means and includes a particle size of less than 1  $\mu\text{m}$ , such as less than or equal to about 500 nanometers (nm), or less than or equal to about 250 nm. In addition, each of the discrete particles may individually exhibit a desired shape, such as one or more of a spherical shape, a hexahedral shape, an ellipsoidal shape, a cylindrical shape, a conical shape, or an irregular shape.

The discrete particles (e.g., discrete alloy particles and/or discrete elemental particles) of the preliminary powder may be monodisperse, wherein each of the discrete particles exhibits substantially the same size and substantially the same shape, or may be polydisperse, wherein at least one of the discrete particles exhibits one or more of a different particle size and a different shape than at least one other of the discrete particles. In some embodiments, the discrete particles of the preliminary powder have a multi-modal (e.g., bi-modal, tri-modal, etc.) particle (e.g., particle) size distribution. For example, the preliminary powder may include a combination of relatively larger, discrete particles and relatively smaller, discrete particles. The multi-modal particle size distribution of the preliminary powder may, for example, provide the precursor composition with desirable particle packing characteristics for the subsequent formation of a consolidated structure (e.g., supporting substrate) therefrom, as described in further detail below. In additional embodiments, the preliminary powder has a mono-modal particle size distribution. For example, all of the discrete particles of the preliminary powder may exhibit substantially the same particle size.

The WC particles of the WC powder may include stoichiometric quantities or near stoichiometric quantities of W and C. Relative amounts of W and C in the discrete WC particles may be selected at least partially based on amounts and material compositions of the discrete particles of the preliminary powder, the discrete WC particles, and the additive(s) (if any) facilitating the formation of a consolidated structure (e.g., supporting substrate) formed of and including WC particles and a homogenized binder including desirable and predetermined amounts of at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U; at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P; C; and W through the subsequent consolidation process. In some embodiments, each of the discrete WC particles of the WC powder includes stoichiometric amounts of W and C. In additional embodiments, one or more of the discrete WC particles of the WC powder includes an excess amount of C than that stoichiometrically required to form WC. In further embodiments, one or more of the discrete WC particles of the WC powder includes an excess amount of W than that stoichiometrically required to form WC.

Each of the discrete WC particles of the WC powder may individually exhibit a desired particle size, such as a particle size less than or equal to about 1000  $\mu\text{m}$ . The discrete WC particles may comprise, for example, one or more of discrete micro-sized WC particles and discrete nano-sized WC particles. In addition, each of the discrete WC particles may individually exhibit a desired shape, such as one or more of a spherical shape, a hexahedral shape, an ellipsoidal shape, a cylindrical shape, a conical shape, or an irregular shape.

The discrete WC particles of the WC powder may be monodisperse, wherein each of the discrete WC particles exhibits substantially the same size and shape, or may be polydisperse, wherein at least one of the discrete WC particles exhibits one or more of a different particle size and a different shape than at least one other of the discrete WC particles. In some embodiments, the WC powder has a multi-modal (e.g., bi-modal, tri-modal, etc.) particle size distribution. For example, the WC powder may include a combination of relatively larger, discrete WC particles and relatively smaller, discrete WC particles. In additional embodiments, the WC powder has a mono-modal particle



size distribution. For example, all of the discrete WC particles of the WC powder may exhibit substantially the same particle size.

The WC powder, including the discrete WC particles thereof, may be formed by conventional processes, which are not described herein.

The binding agent may comprise any material permitting the precursor composition to retain a desired shape during subsequent processing, and which may be removed (e.g., volatilized off) during the subsequent processing. By way of non-limiting example, the binding agent may comprise an organic compound, such as a wax (e.g., a paraffin wax). In some embodiments, the binding agent of the precursor composition is a paraffin wax.

Amounts of the preliminary powder, the WC powder, and the binding agent employed to form the precursor composition may be selected at least partially based on the configurations (e.g., material compositions, sizes, shapes) of the preliminary powder, and the WC powder facilitating the subsequent formation of the supporting substrate **304** including WC particles and a homogenized binder including desired and predetermined amounts of at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U; at least second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P; C; and W. As a non-limiting example, the precursor composition may comprise from about 5 wt % to about 15 wt % of the preliminary powder, from about 85 wt % to about 95 wt % of the WC powder, and a remainder of the binding agent (e.g., paraffin wax). If the preliminary powder only includes discrete alloy particles, the precursor composition may, for example, include from about 5 wt % to about 15 wt % of the discrete preliminary particles, from about 85 wt % to about 95 wt % discrete of the WC particles, and a remainder of a binding agent. If the preliminary powder only includes first discrete elemental particles of the first element, second discrete elemental particles of the second element, and discrete C particles, the precursor composition may, for example, include from about 85 wt % to about 95 wt % of the discrete WC particles, from about 4 wt % to about 15 wt % of the first discrete elemental particles, from about 0.05 wt % to about 3 wt % of the second discrete elemental particles, and from about 0.013 wt % to about 0.3 wt % of the discrete C particles. In some embodiments, the precursor composition comprises about 88 wt % discrete WC particles and about 12 wt % alloy particles individually comprising the first element, the second element, and a third element selected from C and W. In additional embodiments, the precursor composition comprises about 88 wt % of discrete WC particles; about 10.3 wt % of first discrete elemental particles individually comprising the first element; about 1.6 wt % of second discrete elemental particles individually comprising the second element; and about 0.1 wt % of discrete C particles. In further embodiments, the precursor composition comprises about 88 wt % of discrete WC particles; about 10.7 wt % of first discrete elemental particles of the first element; about 1.2 wt % of second discrete elemental particles of the second element; and about 0.1 wt % of discrete C particles.

The precursor composition may be formed by mixing the preliminary powder, the WC powder, the binding agent, and at least one fluid material (e.g., acetone, heptane, etc.) formulated to dissolve and disperse the binding agent using one or more conventional processes (e.g., conventional milling processes, such as ball milling processes, attritor

milling processes, cryomilling processes, jet milling processes, etc.) to form a mixture thereof. The preliminary powder, the WC powder, the binding agent, and the fluid material may be combined in any order. In some embodiments, the preliminary powder and the WC powder are combined (e.g., using a first milling process), and then the binding agent and fluid material are combined with the resulting mixture (e.g., using a second milling process). During the mixing process, collisions between different particles (e.g., the discrete particles of the preliminary powder, the discrete WC particles of the WC powder, the additive particles (if any), etc.) may cause at least some of the different particles to fracture and/or become welded or smeared together. For example, during the mixing process at least some materials (e.g., elements, alloys) of the discrete particles of the preliminary powder may be transferred to surfaces of the WC particles of the WC powder to form composite particles comprising WC coated with an alloy comprising at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U; at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, and B; and at least one third element selected from C and W. Thereafter, the fluid material may be removed (e.g., evaporated), leaving the binding agent on and around any remaining discrete particles of the preliminary powder, any remaining discrete WC particles of the WC powder, any composite particles (e.g., particles comprising WC coated with an alloy comprising the first element, the second element, and the third element), and any other particles comprising constituents of the discrete particles of the preliminary powder, and the discrete WC particles of the WC powder.

Following the formation of the precursor composition, the precursor composition is subjected to a consolidation process to form a consolidated structure (e.g., the supporting substrate **304**) including WC particles dispersed within a homogenized binder. The homogenized binder may, for example, comprise a substantially homogeneous alloy (e.g., a substantially homogeneous peritectic alloy) of at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U; at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, and B; C; and W. Amounts of the first element, the second element, C, and W in the homogenized binder may at least partially depend on the amounts of the first element, the second element, and the third element included in the precursor composition. For example, the homogenized binder and the precursor composition may include substantially the same amounts of the first element and the second element; and homogenized binder may include different amounts of the third element than the precursor composition resulting from dissolution of W from the WC particles during the consolidation process and the migration from and/or maintenance of C of different components (e.g., precursor alloy particles, WC particles, etc.) during the consolidation process.

The consolidated structure (e.g., the supporting substrate **304**) may be formed to exhibit any desired dimensions and any desired shape. The dimensions and shape of the consolidated structure may at least partially depend upon desired dimensions and desired shapes of a compact structure (e.g., a cutting table, such as a PDC table) to subsequently be formed on and/or attached to the consolidated



structure, as described in further detail below. In some embodiments, the consolidated structure is formed to exhibit a cylindrical column shape. In additional embodiments, the consolidated structure is formed to exhibit a different shape, such as a dome shape, a conical shape, a frusto-conical shape, a rectangular column shape, a pyramidal shape, a frusto-pyramidal shape, a fin shape, a pillar shape, a stud shape, or an irregular shape. Accordingly, the consolidated structure may be formed to exhibit any desired lateral cross-sectional shape including, but not limited to, a circular shape, a semicircular shape, an ovular shape, a tetragonal shape (e.g., square, rectangular, trapezium, trapezoidal, parallelogram, etc.), a triangular shape, an elliptical shape, or an irregular shape.

The consolidation process may include forming the precursor composition into a green structure having a shape generally corresponding to the shape of the consolidated structure, subjecting the green structure to at least one densification process (e.g., a sintering process, a hot isostatic pressing (HIP) process, a sintered-HIP process, a hot pressing process, etc.) to form a consolidated structure including WC particles dispersed within an at least partially (e.g., substantially) homogenized binder, and, optionally, subjecting the consolidated structure to at least one supplemental homogenization process to further homogenize the at least partially homogenized binder. As used herein, the term "green" means unsintered. Accordingly, as used herein, a "green structure" means and includes an unsintered structure comprising a plurality of particles, which may be held together by interactions between one or more materials of the plurality of particles and/or another material (e.g., a binder).

The precursor composition may be formed into the green structure through conventional processes, which are not described in detail herein. For example, the precursor composition may be provided into a cavity of a container (e.g., canister, cup, etc.) having a shape complementary to a desired shape (e.g., a cylindrical column shape) of the consolidated structure, and then the precursor composition may be subjected to at least one pressing process (e.g., a cold pressing process, such as a process wherein the precursor composition is subjected to compressive pressure without substantially heating the precursor composition) to form the green structure. The pressing process may, for example, subject the precursor composition within the cavity of the container to a pressure greater than or equal to about 10 tons per square inch (tons/in<sup>2</sup>), such as within a range of from about 10 tons/in<sup>2</sup> to about 30 tons/in<sup>2</sup>.

Following the formation of the green structure, the binding agent may be removed from the green structure. For example, the green structure may be dewaxed by way of vacuum or flowing hydrogen at an elevated temperature. The resulting (e.g., dewaxed) structure may then be subjected to a partial sintering (e.g., pre-sintering) process to form a brown structure having sufficient strength for the handling thereof.

Following the formation of the brown structure, the brown structure may be subjected to a densification process (e.g., a sintering process, a hot isostatic pressing (HIP) process, a sintered-HIP process, a hot pressing process, etc.) that applies sufficient heat and sufficient pressure to the brown structure to form the consolidated structure including the WC particles dispersed in the at least partially homogenized binder. By way of non-limiting example, the brown structure may be wrapped in a sealing material (e.g., graphite foil), and may then be placed in a container made of a high temperature, self-sealing material. The container may

be filled with a suitable pressure transmission medium (e.g., glass particles, ceramic particles, graphite particles, salt particles, metal particles, etc.), and the wrapped brown structure may be provided within the pressure transmission medium. The container, along with the wrapped brown structure and pressure transmission medium therein, may then be heated to a consolidation temperature facilitating the formation of the homogenized binder under isostatic (e.g., uniform) pressure applied by a press (e.g., a mechanical press, a hydraulic press, etc.) to at least partially (e.g., substantially) consolidate the brown structure and form the consolidated structure. The consolidation temperature may be a temperature greater than the solidus temperature of at least the discrete particles (e.g., discrete alloy particles and/or discrete elemental particles) of the preliminary powder used to form the brown structure (e.g., a temperature greater than or equal to the liquidus temperature of the discrete particles, a temperature between the solidus temperature and the liquidus temperature of the discrete particles, etc.), and the applied pressure may be greater than or equal to about 10 megapascals (MPa) (e.g., greater than or equal to about 50 MPa, greater than or equal to about 100 MPa, greater than or equal to about 250 MPa, greater than or equal to about 500 MPa, greater than or equal to about 750 MPa, greater than or equal to about 1.0 gigapascals (GPa), etc.). During the densification process, one or more elements of the WC particles and/or additive(s) (if any) present in the brown structure may diffuse into and homogeneously intermix with a molten alloy of at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U; at least one or second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, and B; and at least one third element selected from C and W to form the at least partially homogenized binder (e.g., the homogenized alloy binder including the first element, the second element, C, and W) of the consolidated structure.

As previously mentioned, following formation, the consolidated structure may be subjected to a supplemental homogenization process to further homogenize the at least partially homogenized binder thereof. If performed, the supplemental homogenization process may heat the consolidated structure to one or more temperatures above the liquidus temperature of the at least partially homogenized binder thereof for a sufficient period of time to reduce (e.g., substantially eliminate) macrosegregation within the at least partially homogenized binder and provide the resulting further homogenized binder with a single (e.g., only one) melting temperature. In some embodiments, such as in embodiments wherein the preliminary powder is employed to form the consolidated structure comprises discrete elemental particles, the at least partially homogenized binder of the consolidated structure may have multiple (e.g., at least two) melting temperatures following the densification process due to one or more regions of at least partially homogenized binder exhibiting different material composition(s) than one or more other regions of at least partially homogenized binder. Such different regions may, for example, form as a result of efficacy margins in source powder mixing and cold consolidation. In such embodiments, the supplemental homogenization process may substantially melt and homogenize the at least partially homogenized binder to remove the regions exhibiting different material composition(s) and provide the further homogenized binder with only one melting point. Providing the homogenized binder of the consolidated structure with only one melting point may be



advantageous for the subsequent formation of a cutting table using the consolidated structure, as described in further detail below. In additional embodiments, such as in embodiments wherein the at least partially homogenized binder of the consolidated structure is already substantially homogeneous (e.g., does not include regions exhibiting different material composition(s) than other regions thereof) following the densification process, the supplemental homogenization process may be omitted.

Referring next to FIG. 3B, the diamond-containing material **301** (FIG. 3A) and the supporting substrate **304** may be subjected to HTHP processing to form a cutting table **302**. The HTHP processing may include subjecting the diamond-containing material **301** and the supporting substrate **304** to elevated temperatures and elevated pressures in a directly pressurized and/or indirectly heated cell for a sufficient time to convert the discrete diamond particles of the diamond-containing material **301** into inter-bonded diamond particles. The temperatures (e.g., sintering temperature(s)) employed within the heated, pressurized cell may be greater than the solidus temperature (e.g., greater than the solidus temperature and less than or equal to the liquidus temperature, greater than or equal to the liquidus temperature, etc.) of the homogenized binder of the supporting substrate **304**, and pressures within the heated, pressurized cell may be greater than or equal to about 2.0 GPa (e.g., greater than or equal to about 3.0 GPa, such as greater than or equal to about 4.0 GPa, greater than or equal to about 5.0 GPa, greater than or equal to about 6.0 GPa, greater than or equal to about 7.0 GPa, greater than or equal to about 8.0 GPa, or greater than or equal to about 9.0 GPa). The temperature(s) employed during the HTHP processing to form the cutting table **302** at least partially depend on the pressure(s) employed during the HTHP processing, and on the material composition of the homogenized binder of the supporting substrate **304**. Employing pressure(s) above atmospheric pressure (1 atm) during the HTHP processing may affect (e.g., shift) metastability lines (e.g., phase boundaries) of the liquid (L)+diamond (D)+metal carbide (MC) phase field, which may influence (e.g., compel the increase of) the temperature(s) employed to form the cutting table **302**. In addition, the material composition of the homogenized binder of the supporting substrate **304** may affect (e.g., increase, decrease) the melting temperature(s) of the homogenized binder, and may also affect (e.g., shift) the metastability lines of the L+D+MC+ $\kappa$ -carbide phase field, which may also impact (e.g., compel the increase of) the temperature(s) employed to form the cutting table **302**. The diamond-containing material **301** and the supporting substrate **304** may be held at selected temperatures and pressures within the heated, pressurized cell for a sufficient amount of time to facilitate the inter-bonding of the discrete diamond particles of the diamond-containing material **301**, such as a period of time between about 30 seconds and about 20 minutes.

During the HTHP processing, the homogenized binder of the supporting substrate **304** melts and a portion thereof is swept (e.g., mass transported, diffused) into the diamond-containing material **301** (FIG. 3A). The homogenized binder received by the diamond-containing material **301** catalyzes the formation of inter-granular bonds between the discrete diamond particles of the diamond-containing material **301** to form inter-bonded diamond particles, and also facilitates the formation of a thermally stable material (e.g., the thermally stable material **118** previously described with reference to FIG. 2) within interstitial spaces between the inter-bonded diamond particles of the cutting table **302**. When the homogenized binder is in a liquid phase, the second element (e.g.,

one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, and B) of the homogenized binder may reduce the reactivity of the first element (e.g., Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U) of the homogenized binder with C, permitting the first element to catalyze the formation of inter-granular bonds between the discrete diamond particles of the diamond-containing material **301** (FIG. 3A) and also promoting the formation of non-binary carbide precipitates (e.g., ternary  $\kappa$ -carbide precipitates, ternary non- $\kappa$ -carbide precipitates, quaternary  $\kappa$ -carbide precipitates, quaternary non- $\kappa$ -carbide precipitates) within the interstitial spaces between the inter-bonded diamond particles of the cutting table **302**. The thermally stable material of the cutting table **302** may render the cutting table **302** thermally stable without needing to leach the cutting table **302**. For example, the thermally stable material may not significantly promote carbon transformations (e.g., graphite-to-diamond or vice versa) as compared to conventional cutting tables including inter-bonded diamond particles substantially exposed to conventional catalyst materials (e.g., catalytic Co, catalytic Fe, catalytic Ni) within interstitial spaces between the inter-bonded diamond particles. Accordingly, the thermally stable material may render the cutting table **302** more thermally stable than conventional cutting tables.

Since the diamond-containing material **301** (FIG. 3A) is provided directly on the supporting substrate **304**, the types, amounts, and distributions of individual elements swept into the diamond-containing material **301** during the HTHP processing is substantially the same as the types, amounts, and distributions of individual elements of the homogenized binder of the supporting substrate **304**. Put another way, the material composition (including the types, amounts, and distributions of the individual elements thereof) of the homogenized binder diffused into the diamond-containing material **301** during the HTHP processing to form the cutting table **302** is substantially the same as the material composition of homogenized binder within the supporting substrate **304** prior to the HTHP processing. For example, if the homogenized binder of the supporting substrate **304** comprises a ratio of at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U to at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, and B of about 9:1, a ratio of the first element to the second element swept into to the diamond-containing material **301** during the HTHP processing will also be about 9:1. Accordingly, providing the diamond-containing material **301** directly on the supporting substrate **304** may ensure that desired and predetermined sweep chemistries are provided into the diamond-containing material **301** during the HTHP processing.

In addition, providing the diamond-containing material **301** (FIG. 3A) directly on the supporting substrate **304** may reduce melting-point-based complexities associated with providing desired sweep chemistries into the diamond-containing material **301** during the HTHP processing as compared to configurations wherein a structure having a different material composition than the homogenized binder of the supporting substrate **304** is provided between the diamond-containing material **301** and the supporting substrate **304**. For example, providing the diamond-containing material **301** directly on the supporting substrate **304** may permit a desired material composition (e.g., the material composition of the homogenized binder of the supporting



substrate 304) to be swept into the diamond-containing material 301 using a single temperature (e.g., the melting temperature of the homogenized binder) and/or a relatively narrower temperature range, whereas providing a structure between the diamond-containing material 301 and the supporting substrate 304 may require exposing the diamond-containing material 301, the structure, and the supporting substrate 304 to multiple temperatures (e.g., the melting temperature of the structure, and the melting temperature of the homogenized binder of the supporting substrate 304) and/or a relatively wider temperature range to permit a desired material composition (e.g., a combination of the material compositions of the structure and the homogenized binder of the supporting substrate 304) to be swept into the diamond-containing material 301 during the HTHP processing.

Optionally, following formation, the cutting table 302 may be subjected to at least one solution treatment process to modify the material composition of the thermally stable material thereof. The solution treatment process may, for example, decompose carbide precipitates (e.g.,  $\kappa$ -carbide precipitates, non- $\kappa$ -carbide precipitates) of the thermally stable material into one or more other precipitates. By way of non-limiting example, if at least the homogenized binder of the supporting substrate 304 effectuates the formation of a thermally stable material including  $\kappa$ -carbide precipitates in the cutting table 302, the cutting table 302 may optionally be subjected to a solution treatment process that heats the thermally stable material at least to a decomposition temperature of the  $\kappa$ -carbide precipitates (e.g., a temperature greater than or equal to about 1000° C., such as from about 1000° C. to about 1500° C., or from about 1300° C. to about 1500° C.) at a pressure above the Berman-Simon line to decompose the  $\kappa$ -carbide precipitates and form FCC L1<sub>2</sub> phase precipitates. If employed, the cutting table 302 may be subjected to a single (e.g., only one) solution treatment process employing a single temperature under pressure above the Berman-Simon line, or may be subjected to multiple (e.g., more than one) solution treatment processes employing different temperatures under pressure above the Berman-Simon line. Multiple solution treatment processes at different temperatures may, for example, facilitate the formation of precipitates (e.g., FCC L1<sub>2</sub> phase precipitates) having different particle sizes than one another. Relatively larger precipitate sizes may enhance high-temperature properties (e.g., creep rupture properties) of the thermally stable material, and relatively smaller precipitate sizes may enhance room-temperature properties of the thermally stable material.

In additional embodiments, the cutting element 100 previously described with reference to FIG. 1 may be formed through methods other than that described with reference to FIGS. 3A and 3B. For example, an embodiment of another method of forming the cutting element 100 (FIG. 1) will now be described with reference to FIGS. 4A and 4B, which illustrate simplified cross-sectional views of a container 400 in another process of forming the cutting element 100 shown in FIG. 1. With the description provided below, it will be readily apparent to one of ordinary skill in the art that the methods described herein may be used in various devices. In other words, the methods of the disclosure may be used whenever it is desired to form a thermally stable structure, such as a thermally stable cutting table (e.g., a thermally stable diamond table, such as a thermally stable PDC), for an earth-boring tool.

Referring to FIG. 4A, a diamond-containing material 401 may be provided within the container 400, and a supporting

substrate 404 may be provided on or over the diamond-containing material 401. The container 400 may substantially surround and hold the diamond-containing material 401 and the supporting substrate 404. As shown in FIG. 4A, the container 400 may include an inner cup 408 in which the diamond-containing material 401 and a portion of the supporting substrate 404 may be disposed, a bottom end piece 406 in which the inner cup 408 may be at least partially disposed, and a top end piece 410 surrounding the supporting substrate 404 and coupled (e.g., swage bonded) to one or more of the inner cup 408 and the bottom end piece 406. In additional embodiments, the bottom end piece 406 may be omitted (e.g., absent).

The diamond-containing material 401 (e.g., diamond powder) may be formed of and include discrete diamond particles, and discrete alloy particles formulated to facilitate the formation of a compact structure (e.g., a cutting table, such as a PDC table) including inter-bonded diamond particles and a thermally stable material (e.g., the thermally stable material 118 previously described with reference to FIG. 2) within interstitial spaces between the inter-bonded diamond particles (e.g., the inter-bonded diamond particles 114 of the cutting table 102 previously described with reference to FIG. 2) following subsequent HTHP processing.

The discrete diamond particles of the diamond-containing material 401 may comprise one or more of discrete natural diamond particles, and discrete synthetic diamond particles. The discrete diamond particles may individually exhibit a desired particle size. The discrete diamond particles may comprise, for example, one or more of micro-sized diamond particles and nano-sized diamond particles. In addition, each of the discrete diamond particles may individually exhibit a desired shape, such as at least one of a spherical shape, a hexahedral shape, an ellipsoidal shape, a cylindrical shape, a conical shape, or an irregular shape. In some embodiments, each of the discrete diamond particles of the diamond-containing material 401 exhibits a substantially spherical shape. The discrete diamond particles may be monodisperse, wherein each of the discrete diamond particles exhibits substantially the same material composition, size, and shape, or may be polydisperse, wherein at least one of the discrete diamond particles exhibits one or more of a different material composition, a different particle size, and a different shape than at least one other of the discrete diamond particles. The discrete diamond particles may be formed by conventional processes, which are not described herein.

The discrete alloy particles of the diamond-containing material 401 may individually be formed of and include a homogenized alloy (e.g., a homogenized peritectic alloy) of at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U, and at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P. The discrete alloy particles may each individually include any amounts of the first element and the second element able to facilitate (e.g., catalyze) the inter-bonding of the discrete diamond particles during subsequent HTHP processing, and able to facilitate the formation of a thermally stable material (e.g., the thermally stable material 118 previously described with reference to FIG. 2) within interstitial spaces between the inter-bonded diamond particles (e.g., the inter-bonded diamond particles 114 previously described with reference to FIG. 2). The discrete alloy particles of the diamond-containing material 401 may each individually have a liquidus temperature



greater than or equal to about 525° C., such as within a range of from about 525° C. to about 1500° C. By way of non-limiting example, each of the discrete alloy particles may individually comprise a homogenized alloy selected from Sm<sub>3</sub>Sn, Sm<sub>3</sub>Bi, Sm<sub>3</sub>Te, Sm<sub>3</sub>P, Sm<sub>3</sub>Si, Sm<sub>3</sub>Ga, Sc<sub>3</sub>Sn, Sc<sub>3</sub>Ge, Sc<sub>3</sub>Sb, Sc<sub>3</sub>As, Sm<sub>3</sub>Be, Sc<sub>3</sub>P, Sc<sub>3</sub>Si, Y<sub>3</sub>Sn, Sc<sub>3</sub>Bi, Tm<sub>3</sub>Sn, Er<sub>3</sub>Sn, Sc<sub>3</sub>Te, Y<sub>3</sub>Sb, Sc<sub>3</sub>Se, Ho<sub>3</sub>Sn, Sc<sub>3</sub>Ga, Dy<sub>3</sub>Sn, Y<sub>3</sub>Bi, Tb<sub>3</sub>Sn, Tm<sub>3</sub>Sb, Er<sub>3</sub>Sb, Lu<sub>3</sub>Sb, Lu<sub>3</sub>Ge, Ti<sub>3</sub>Ga, Ti<sub>3</sub>Ge, Gd<sub>3</sub>Sn, Tb<sub>3</sub>Sb, Y<sub>3</sub>Ge, Er<sub>3</sub>Bi, Ho<sub>3</sub>Bi, Tm<sub>3</sub>Bi, Lu<sub>3</sub>As, Tm<sub>3</sub>Ge, Dy<sub>3</sub>Bi, Lu<sub>3</sub>Bi, Tm<sub>3</sub>As, Tb<sub>3</sub>Bi, Ti<sub>3</sub>Sn, Er<sub>3</sub>As, Ti<sub>3</sub>Si, Y<sub>3</sub>Te, Gd<sub>3</sub>Bi, Ce<sub>3</sub>Te, Ti<sub>3</sub>Al, Zr<sub>3</sub>Sn, Dy<sub>3</sub>As, La<sub>3</sub>Bi, Sc<sub>3</sub>Al, Yb<sub>3</sub>Se, Tb<sub>3</sub>As, Lu<sub>3</sub>P, Yb<sub>3</sub>Te, Lu<sub>3</sub>Sn, Eu<sub>3</sub>Se, Er<sub>3</sub>Te, Ti<sub>3</sub>Sb, Lu<sub>3</sub>Si, Tm<sub>3</sub>Te, Tm<sub>3</sub>P, Gd<sub>3</sub>Te, Gd<sub>3</sub>As, Zr<sub>3</sub>Sb, Lu<sub>3</sub>Ga, Er<sub>3</sub>P, Sm<sub>3</sub>B, Lu<sub>3</sub>Te, Ho<sub>3</sub>P, Tm<sub>3</sub>Si, Er<sub>3</sub>Si, Dy<sub>3</sub>P, Tm<sub>3</sub>Ga, Ce<sub>3</sub>As, Y<sub>3</sub>Ga, Ho<sub>3</sub>Si, Tb<sub>3</sub>P, Er<sub>3</sub>Ga, Dy<sub>3</sub>Si, Eu<sub>3</sub>Bi, Hf<sub>3</sub>Ga, Ho<sub>3</sub>Ga, Gd<sub>3</sub>P, Gd<sub>3</sub>Se, Lu<sub>3</sub>Al, Ce<sub>3</sub>Sn, Tb<sub>3</sub>Si, Hf<sub>3</sub>Sn, Dy<sub>3</sub>Ga, Tm<sub>3</sub>Al, Gd<sub>3</sub>Si, Ti<sub>3</sub>Bi, Tb<sub>3</sub>Ga, Er<sub>3</sub>Al, Yb<sub>3</sub>Bi, Yb<sub>3</sub>Sb, La<sub>3</sub>P, Eu<sub>3</sub>As, Fe<sub>3</sub>Al, Ho<sub>3</sub>Al, Gd<sub>3</sub>Ga, Yb<sub>3</sub>As, Tb<sub>3</sub>Bi, Ac<sub>3</sub>Sb, Th<sub>3</sub>Sn, Tb<sub>3</sub>Al, Eu<sub>3</sub>P, Fe<sub>3</sub>Si, Ti<sub>3</sub>Be, Yb<sub>3</sub>P, Gd<sub>3</sub>Al, Hf<sub>3</sub>P, V<sub>3</sub>Si, Ce<sub>3</sub>Si, V<sub>3</sub>Ge, Fe<sub>3</sub>Ga, Rh<sub>3</sub>Al, Th<sub>3</sub>Ge, V<sub>3</sub>Al, Fe<sub>3</sub>Ge, V<sub>3</sub>Ga, Th<sub>3</sub>P, V<sub>3</sub>P, V<sub>3</sub>Sn, Fe<sub>3</sub>Sn, Zr<sub>3</sub>Be, Hf<sub>3</sub>Be, Nb<sub>3</sub>Ga, Sc<sub>3</sub>Be, Th<sub>3</sub>Al, V<sub>3</sub>Sb, Ce<sub>3</sub>Al, Co<sub>3</sub>Al, V<sub>3</sub>As, Ni<sub>3</sub>Al, Co<sub>3</sub>Ga, Ti<sub>3</sub>B, Rh<sub>3</sub>Ga, Fe<sub>3</sub>Be, Fe<sub>3</sub>Sb, Sc<sub>3</sub>B, U<sub>3</sub>P, Fe<sub>3</sub>P, Co<sub>3</sub>Si, Hf<sub>3</sub>Bi, V<sub>3</sub>Be, V<sub>3</sub>Te, Ni<sub>3</sub>Ga, Lu<sub>3</sub>Be, Mn<sub>3</sub>Al, Ru<sub>3</sub>Al, Fe<sub>3</sub>As, Ta<sub>3</sub>Sn, Mn<sub>3</sub>Si, V<sub>3</sub>Se, U<sub>3</sub>Se, Co<sub>3</sub>Sn, Co<sub>3</sub>Be, Co<sub>3</sub>Ge, U<sub>3</sub>Si, Cr<sub>3</sub>Si, V<sub>3</sub>Bi, Tc<sub>3</sub>Al, La<sub>3</sub>Si, Rh<sub>3</sub>Sn, Cr<sub>3</sub>Al, U<sub>3</sub>As, Mn<sub>3</sub>Ga, Th<sub>3</sub>Si, Rh<sub>3</sub>Be, Ni<sub>3</sub>Be, Mn<sub>3</sub>Ge, Cr<sub>3</sub>Ge, Pd<sub>3</sub>Al, and Cr<sub>3</sub>Ga. In some embodiments, the discrete alloy particles are substantially free of Co. In additional embodiments, the discrete alloy particles are substantially free of Ni. In further embodiments, the discrete alloy particles are substantially free of Fe. In still further embodiments, the discrete alloy particles are substantially free of each of Co, Ni, and Fe. Each of the discrete alloy particles may include substantially the same elements and element ratios of as each other of the discrete alloy particles, or one or more of the discrete alloy particles may include different elements and/or different element ratios than one or more other of the discrete alloy particles. In some embodiments, each of the discrete alloy particles has substantially the same elements and element ratios as each other of the discrete alloy particles.

Each of the discrete alloy particles of the diamond-containing material **401** may individually exhibit a desired particle size, such as a particle size less than or equal to about 1000 μm. The discrete alloy particles may comprise, for example, one or more of discrete micro-sized particles and discrete nano-sized particles. In addition, each of the discrete alloy particles of the diamond-containing material **401** may individually exhibit a desired shape, such as one or more of a spherical shape, a hexahedral shape, an ellipsoidal shape, a cylindrical shape, a conical shape, or an irregular shape. The discrete particles of the diamond-containing material **401** may be monodisperse, wherein each of the discrete alloy particles exhibits substantially the same size and substantially the same shape, or may be polydisperse, wherein at least one of the discrete alloy particles exhibits one or more of a different particle size and a different shape than at least one other of the discrete alloy particles. In some embodiments, the discrete alloy particles of the diamond-containing material **401** have a multi-modal (e.g., bi-modal, tri-modal, etc.) particle size distribution. For example, the diamond-containing material **401** may include a combination of relatively larger, discrete alloy particles and relatively smaller, discrete alloy particles. In additional embodiments, the discrete alloy particles of the diamond-containing material **401** have a mono-modal particle size distribution.

The discrete alloy particles of the diamond-containing material **401** may be formed by conventional processes (e.g., ball milling processes, attritor milling processes, cryomilling processes, jet milling processes, powder atomization processes, etc.), which are not described herein. As a non-limiting example, an initial powder formed of and including particles of at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U, and at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P, alloys thereof, and/or combinations thereof may be provided into an attritor mill containing mixing structures (e.g., mixing spheres, mixing bars, etc.), and may then be subjected to a mechanical alloying process until the discrete alloy particles are formed. During the mechanical alloying process collisions between the mixing structures and the initial powder may cause particles of different materials to fracture and/or be welded or smeared together. Relatively larger particles may fracture during the mechanical welding process and relatively smaller particles may weld together, eventually forming discrete alloy particles each individually comprising a substantially homogeneous mixture of the constituents of the initial powder in substantially the same proportions of the initial powder. As another non-limiting example, an alloy material may be formed by conventional melting and mixing processes, and then the alloy material may be formed into the discrete alloy particles by one or more conventional atomization processes.

The diamond-containing material **401** may exhibit a substantially homogeneous distribution of the discrete diamond particles and the discrete alloy particles. The discrete diamond particles and the discrete alloy particles may be combined (e.g., mixed) with one another to form the diamond-containing material **401** exhibiting the substantially homogeneous distribution of the discrete diamond particles and the discrete alloy particles using conventional processes (e.g., conventional milling processes, such as conventional ball milling processes, conventional attritor milling processes, conventional cryomilling processes, conventional jet milling processes, etc.), which are not described in detail herein.

The supporting substrate **404** may be formed of and include a material that is relatively hard and resistant to wear. By way of non-limiting example, the supporting substrate **404** may be formed from and include a ceramic-metal composite material (also referred to as a “cermet” material). In some embodiments, the supporting substrate **404** is formed of and includes a cemented carbide material including carbide particles cemented together in a binder material. The carbide particles of the supporting substrate **404** may, for example, individually include one or more chemical compounds of W and C, such as WC, W<sub>2</sub>C, or combinations of WC and W<sub>2</sub>C. In some embodiments, the carbide particles comprise WC particles each including stoichiometric quantities or near stoichiometric quantities of W and C. In additional embodiments, one or more of the carbide particles includes an excess amount of C than that stoichiometrically required to form WC. In further embodiments, one or more of the carbide particles includes an excess amount of W than that stoichiometrically required to form WC. The binder material of the supporting substrate **404** may comprise a catalytic binder material formulated to promote the formation of the inter-bonded diamond particles from discrete diamond particles during HTHP processing, or may comprise a non-catalytic binder material that does not



promote the formation of the inter-bonded diamond particles from discrete diamond particles during HTHP processing. The supporting substrate **404** may have a material composition substantially the same as that of the supporting substrate **304** previously described with reference to FIGS. **3A** and **3B**, or may have a different material composition than that of the supporting substrate **304** previously described with reference to FIGS. **3A** and **3B**.

Referring next to FIG. **4B**, the diamond-containing material **401** (FIG. **4A**) and the supporting substrate **404** may be subjected to HTHP processing to form a cutting table **402**. The HTHP processing may include subjecting the diamond-containing material **401** and the supporting substrate **404** to elevated temperatures and elevated pressures in a directly pressurized and/or indirectly heated cell for a sufficient time to convert the discrete diamond particles of the diamond-containing material **401** into inter-bonded diamond particles. The temperatures (e.g., sintering temperature(s)) employed within the heated, pressurized cell may be greater than the solidus temperature (e.g., greater than the solidus temperature and less than or equal to the liquidus temperature, greater than or equal to the liquidus temperature, etc.) of the discrete alloy particles of the diamond-containing material **401**, and pressures within the heated, pressurized cell may be greater than or equal to about 2.0 GPa (e.g., greater than or equal to about 3.0 GPa, such as greater than or equal to about 4.0 GPa, greater than or equal to about 5.0 GPa, greater than or equal to about 6.0 GPa, greater than or equal to about 7.0 GPa, greater than or equal to about 8.0 GPa, or greater than or equal to about 9.0 GPa). The temperature(s) employed during the HTHP processing to form the cutting table **402** at least partially depend on the pressure(s) employed during the HTHP processing, and on the material composition of the discrete alloy particles of the diamond-containing material **401**. Employing pressure(s) above atmospheric pressure (1 atm) during the HTHP processing may affect (e.g., shift) metastability lines (e.g., phase boundaries) of the liquid (L)+diamond (D)+metal carbide (MC) phase field, which may influence (e.g., compel the increase of) the temperature(s) employed to form the cutting table **402**. In addition, the material composition of the discrete alloy particles of the diamond-containing material **401** may affect (e.g., increase, decrease) the melting temperature(s) of the discrete alloy particles, and may also affect (e.g., shift) the metastability lines of the L+D+MC+ $\kappa$ -carbide phase field, which may also impact (e.g., compel the increase of) the temperature(s) employed to form the cutting table **402**. The diamond-containing material **401** and the supporting substrate **404** may be held at selected temperatures and pressures within the heated, pressurized cell for a sufficient amount of time to facilitate the inter-bonding of the discrete diamond particles of the diamond-containing material **401**, such as a period of time between about 30 seconds and about 20 minutes.

During the HTHP processing, the discrete alloy particles of the diamond-containing material **401** (FIG. **4A**) melt and catalyze the formation of inter-granular bonds between the discrete diamond particles of the diamond-containing material **401** to form the inter-bonded diamond particles of the cutting table **402**, and also facilitate the formation of a thermally stable material (e.g., the thermally stable material **118** previously described with reference to FIG. **2**) within interstitial spaces between the inter-bonded diamond particles of the cutting table **402**. When the homogenized alloy of the discrete alloy particles is in a liquid phase, the second element (e.g., one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, and B) of the homogenized alloy may reduce the

reactivity of the first element (e.g., Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U) of the homogenized alloy with C, permitting the first element to catalyze the formation of inter-granular bonds between the discrete diamond particles of the diamond-containing material **401** and also promoting the formation of non-binary carbide precipitates (e.g., ternary  $\kappa$ -carbide precipitates, ternary non- $\kappa$ -carbide precipitates, quaternary  $\kappa$ -carbide precipitates, quaternary non- $\kappa$ -carbide precipitates) within the interstitial spaces between the inter-bonded diamond particles of the cutting table **402**. Even if the first element comprises an element (e.g., Co, Ni, Ag, Cu, Au, Pt, Tc) that is not highly reactive with C to form a binary carbide, the second element may enhance the stability properties (e.g., thermal stability properties, mechanical stability properties) of the cutting table **402** by facilitating the formation of carbide precipitates (e.g.,  $\kappa$ -carbide precipitates, non- $\kappa$ -carbide precipitates) having formula (1) above. The thermally stable material of the cutting table **402** may render the cutting table **402** thermally stable without needing to leach the cutting table **402**. For example, the thermally stable material may not significantly promote carbon transformations (e.g., graphite-to-diamond or vice versa) as compared to conventional cutting tables including inter-bonded diamond particles substantially exposed to conventional catalyst materials (e.g., catalytic Co, catalytic Fe, catalytic Ni) within interstitial spaces between the inter-bonded diamond particles. Accordingly, the thermally stable material may render the cutting table **402** more thermally stable than conventional cutting tables.

Optionally, following formation, the cutting table **402** may be subjected to at least one solution treatment process to modify the material composition of the thermally stable material thereof. The solution treatment process may, for example, decompose carbide precipitates (e.g.,  $\kappa$ -carbide precipitates, non- $\kappa$ -carbide precipitates) of the thermally stable material into one or more other precipitates. By way of non-limiting example, if at least the discrete alloy particles of the diamond-containing material **401** (FIG. **4A**) effectuate the formation of a thermally stable material including  $\kappa$ -carbide precipitates in the cutting table **402**, the cutting table **402** may optionally be subjected to a solution treatment process that heats the thermally stable material at least to a decomposition temperature of the  $\kappa$ -carbide precipitates (e.g., a temperature greater than or equal to about 1000° C., such as from about 1000° C. to about 1500° C., or from about 1300° C. to about 1500° C.) at a pressure above the Berman-Simon line to decompose the  $\kappa$ -carbide precipitates and form FCC L1<sub>2</sub> phase precipitates. If employed, the cutting table **402** may be subjected to a single (e.g., only one) solution treatment process employing a single temperature under pressure above the Berman-Simon line, or may be subjected to multiple (e.g., more than one) solution treatment processes employing different temperatures under pressure above the Berman-Simon line. Multiple solution treatment processes at different temperatures may, for example, facilitate the formation of precipitates (e.g., FCC L1<sub>2</sub> phase precipitates) having different particle sizes than one another. Relatively larger precipitate sizes may enhance high-temperature properties (e.g., creep rupture properties) of the thermally stable material, and relatively smaller precipitate sizes may enhance room-temperature properties of the thermally stable material.

In further embodiments, the cutting element **100** previously described with reference to FIG. **1** may be formed



through methods other than those previously described with reference to FIGS. 3A and 3B and with reference to FIGS. 4A and 4B. For example, an embodiment of another method of forming the cutting element 100 (FIG. 1) will now be described with reference to FIGS. 5A and 5B, which illustrate simplified cross-sectional views of a container 500 in another process of forming the cutting element 100 shown in FIG. 1. With the description provided below, it will be readily apparent to one of ordinary skill in the art that the methods described herein may be used in various devices. In other words, the methods of the disclosure may be used whenever it is desired to form a thermally stable structure, such as a thermally stable cutting table (e.g., a thermally stable diamond table, such as a thermally stable PDC), for an earth-boring tool.

Referring to FIG. 5A, a diamond-containing material 501 may be provided within the container 500, a supporting substrate 504 may be provided on or over the diamond-containing material 501, and an alloy material 513 on at least the diamond-containing material 501. The container 500 may substantially surround and hold the diamond-containing material 501, the supporting substrate 504, and the alloy material 513. As shown in FIG. 5A, the container 500 may include an inner cup 508 in which the diamond-containing material 501, the alloy material 513, and a portion of the supporting substrate 504 may be disposed; a bottom end piece 506 in which the inner cup 508 may be at least partially disposed; and a top end piece 510 surrounding the supporting substrate 504 and coupled (e.g., swage bonded) to one or more of the inner cup 508 and the bottom end piece 506. In additional embodiments, the bottom end piece 506 may be omitted (e.g., absent).

The diamond-containing material 501 (e.g., diamond powder) may be formed of and include discrete diamond particles (e.g., discrete natural diamond particles, discrete synthetic diamond particles, combinations thereof, etc.). The discrete diamond particles may individually exhibit a desired particle size. The discrete diamond particles may comprise, for example, one or more of micro-sized diamond particles and nano-sized diamond particles. In addition, each of the discrete diamond particles may individually exhibit a desired shape, such as at least one of a spherical shape, a hexahedral shape, an ellipsoidal shape, a cylindrical shape, a conical shape, or an irregular shape. In some embodiments, each of the discrete diamond particles of the diamond-containing material 501 exhibits a substantially spherical shape. The discrete diamond particles may be monodisperse, wherein each of the discrete diamond particles exhibits substantially the same material composition, size, and shape, or may be polydisperse, wherein at least one of the discrete diamond particles exhibits one or more of a different material composition, a different particle size, and a different shape than at least one other of the discrete diamond particles. The diamond-containing material 501 may have a material composition substantially the same as that of the diamond-containing material 301 previously described with reference to FIGS. 3A and 3B, may have a material composition substantially the same as that of the diamond-containing material 401 previously described with reference to FIGS. 4A and 4B, or may have a material composition different than that of each of the diamond-containing material 301 previously described with reference to FIGS. 3A and 3B and the diamond-containing material 401 previously described with reference to FIGS. 4A and 4B. In some embodiments, the diamond-containing material 501 is substantially free of discrete alloy particles dispersed amongst the discrete diamond particles thereof. The diamond-con-

taining material 501 may be formed by conventional processes, which are not described herein.

The supporting substrate 504 may be formed of and include a material that is relatively hard and resistant to wear. By way of non-limiting example, the supporting substrate 504 may be formed from and include a ceramic-metal composite material. In some embodiments, the supporting substrate 504 is formed of and includes a cemented carbide material including carbide particles cemented together in a binder material. The carbide particles of the supporting substrate 504 may, for example, individually include one or more chemical compounds of W and C, such as WC,  $W_2C$ , or combinations of WC and  $W_2C$ . In some embodiments, the carbide particles comprise WC particles each including stoichiometric quantities or near stoichiometric quantities of W and C. In additional embodiments, one or more of the carbide particles include an excess amount of C than that stoichiometrically required to form WC. In further embodiments, one or more of the carbide particles includes an excess amount of W than that stoichiometrically required to form WC. The binder material of the supporting substrate 404 may comprise a catalytic binder material formulated to promote the formation of the inter-bonded diamond particles from discrete diamond particles during HTHP processing, or may comprise a non-catalytic binder material that does not promote the formation of the inter-bonded diamond particles from discrete diamond particles during HTHP processing. The supporting substrate 504 may have a material composition substantially the same as that of the supporting substrate 304 previously described with reference to FIGS. 3A and 3B, may have a material composition substantially the same as that of the supporting substrate 404 previously described with reference to FIGS. 4A and 4B, or may have a material composition different than that of each of the supporting substrate 304 previously described with reference to FIGS. 3A and 3B and the supporting substrate 404 previously described with reference to FIGS. 4A and 4B.

The alloy material 513 may be provided directly adjacent one or more outermost (e.g., peripheral) boundaries of the diamond-containing material 501. The alloy material 513 may be provided directly adjacent opposing outermost boundaries of the diamond-containing material 501 and the supporting substrate 504, such that at least a portion of the alloy material 513 intervenes between the diamond-containing material 501 and the supporting substrate 504; and/or may be provided directly adjacent outermost boundaries of the diamond-containing material 501 not opposing an outermost boundary of the supporting substrate 504, such that at least a portion of the alloy material 513 does not intervene between the diamond-containing material 501 and the supporting substrate 504. For example, as shown in FIG. 5A, a first volume 513A of the alloy material 513 may be located directly adjacent opposing outermost boundaries of the diamond-containing material 501 and the supporting substrate 504, and a second volume 513B of the alloy material 513 may be located directly adjacent one or more other outermost boundaries of the diamond-containing material 501. In some embodiments, the alloy material 513 only includes the first volume 513A, such that the alloy material 513 is located directly adjacent opposing outermost boundaries of the diamond-containing material 501 and the supporting substrate 504, but does not substantially cover any other outermost boundaries of the diamond-containing material 501. In additional embodiments, the alloy material 513 only includes the second volume 513B, such that the alloy material 513 does not substantially intervene between



diamond-containing material **501** and the supporting substrate **504**, but does cover at least some other outermost boundaries (e.g., another outermost vertical boundary, outermost lateral boundaries) of the diamond-containing material **501**. In further embodiments, the alloy material **513** includes the first volume **513A** and the second volume **513B**.

The alloy material **513** may be formed of and include at least one homogenized alloy (e.g., a homogenized peritectic alloy) of at least one first element selected from Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U, and at least one second element selected from Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P. The homogenized alloy may include any amounts of the first element and the second element able to facilitate (e.g., catalyze) the inter-bonding of the discrete diamond particles during subsequent HTHP processing, and able to facilitate the formation of a thermally stable material (e.g., the thermally stable material **118** previously described with reference to FIG. 2) within interstitial spaces between the inter-bonded diamond particles (e.g., the inter-bonded diamond particles **114** previously described with reference to FIG. 2). The homogenized alloy of the alloy material **513** may have a liquidus temperature greater than or equal to about 525° C., such as within a range of from about 525° C. to about 1500° C. By way of non-limiting example, the homogenized alloy may be selected from Sm<sub>3</sub>Sn, Sm<sub>3</sub>Bi, Sm<sub>3</sub>Te, Sm<sub>3</sub>P, Sm<sub>3</sub>Si, Sm<sub>3</sub>Ga, Sc<sub>3</sub>Sn, Sc<sub>3</sub>Ge, Sc<sub>3</sub>Sb, Sc<sub>3</sub>As, Sm<sub>3</sub>Be, Sc<sub>3</sub>P, Sc<sub>3</sub>Si, Y<sub>3</sub>Sn, Sc<sub>3</sub>Bi, Tm<sub>3</sub>Sn, Er<sub>3</sub>Sn, Sc<sub>3</sub>Te, Y<sub>3</sub>Sb, Sc<sub>3</sub>Se, Ho<sub>3</sub>Sn, Sc<sub>3</sub>Ga, Dy<sub>3</sub>Sn, Y<sub>3</sub>Bi, Tb<sub>3</sub>Sn, Tm<sub>3</sub>Sb, Er<sub>3</sub>Sb, Lu<sub>3</sub>Sb, Lu<sub>3</sub>Ge, Ti<sub>3</sub>Ga, Ti<sub>3</sub>Ge, Gd<sub>3</sub>Sn, Tb<sub>3</sub>Sb, Y<sub>3</sub>Ge, Er<sub>3</sub>Bi, Ho<sub>3</sub>Bi, Tm<sub>3</sub>Bi, Lu<sub>3</sub>As, Tm<sub>3</sub>Ge, Dy<sub>3</sub>Bi, Lu<sub>3</sub>Bi, Tm<sub>3</sub>As, Tb<sub>3</sub>Bi, Ti<sub>3</sub>Sn, Er<sub>3</sub>As, Ti<sub>3</sub>Si, Y<sub>3</sub>Te, Gd<sub>3</sub>Bi, Ce<sub>3</sub>Te, Ti<sub>3</sub>Al, Zr<sub>3</sub>Sn, Dy<sub>3</sub>As, La<sub>3</sub>Bi, Sc<sub>3</sub>Al, Yb<sub>3</sub>Se, Tb<sub>3</sub>As, Lu<sub>3</sub>P, Yb<sub>3</sub>Te, Lu<sub>3</sub>Sn, Eu<sub>3</sub>Se, Er<sub>3</sub>Te, Ti<sub>3</sub>Sb, Lu<sub>3</sub>Si, Tm<sub>3</sub>Te, Tm<sub>3</sub>P, Gd<sub>3</sub>Te, Gd<sub>3</sub>As, Zr<sub>3</sub>Sb, Lu<sub>3</sub>Ga, Er<sub>3</sub>P, Sm<sub>3</sub>B, Lu<sub>3</sub>Te, Ho<sub>3</sub>P, Tm<sub>3</sub>Si, Er<sub>3</sub>Si, Dy<sub>3</sub>P, Tm<sub>3</sub>Ga, Ce<sub>3</sub>As, Y<sub>3</sub>Ga, Ho<sub>3</sub>Si, Tb<sub>3</sub>P, Er<sub>3</sub>Ga, Dy<sub>3</sub>Si, Eu<sub>3</sub>Bi, Hf<sub>3</sub>Ga, Ho<sub>3</sub>Ga, Gd<sub>3</sub>P, Gd<sub>3</sub>Se, Lu<sub>3</sub>Al, Ce<sub>3</sub>Sn, Tb<sub>3</sub>Si, Hf<sub>3</sub>Sn, Dy<sub>3</sub>Ga, Tm<sub>3</sub>Al, Gd<sub>3</sub>Si, Ti<sub>3</sub>Bi, Tb<sub>3</sub>Ga, Er<sub>3</sub>Al, Yb<sub>3</sub>Bi, Yb<sub>3</sub>Sb, La<sub>3</sub>P, Eu<sub>3</sub>As, Fe<sub>3</sub>Al, Ho<sub>3</sub>Al, Gd<sub>3</sub>Ga, Yb<sub>3</sub>As, Th<sub>3</sub>Bi, Ac<sub>3</sub>Sb, Th<sub>3</sub>Sn, Tb<sub>3</sub>Al, Eu<sub>3</sub>P, Fe<sub>3</sub>Si, Ti<sub>3</sub>Be, Yb<sub>3</sub>P, Gd<sub>3</sub>Al, Hf<sub>3</sub>P, V<sub>3</sub>Si, Ce<sub>3</sub>Si, V<sub>3</sub>Ge, Fe<sub>3</sub>Ga, Rh<sub>3</sub>Al, Th<sub>3</sub>Ge, V<sub>3</sub>Al, Fe<sub>3</sub>Ge, V<sub>3</sub>Ga, Th<sub>3</sub>P, V<sub>3</sub>P, V<sub>3</sub>Sn, Fe<sub>3</sub>Sn, Zr<sub>3</sub>Be, Hf<sub>3</sub>Be, Nb<sub>3</sub>Ga, Sc<sub>3</sub>Be, Th<sub>3</sub>Al, V<sub>3</sub>Sb, Ce<sub>3</sub>Al, Co<sub>3</sub>Al, V<sub>3</sub>As, Ni<sub>3</sub>Al, Co<sub>3</sub>Ga, Ti<sub>3</sub>B, Rh<sub>3</sub>Ga, Fe<sub>3</sub>Be, Fe<sub>3</sub>Sb, Sc<sub>3</sub>B, U<sub>3</sub>P, Fe<sub>3</sub>P, Co<sub>3</sub>Si, Hf<sub>3</sub>Bi, V<sub>3</sub>Be, V<sub>3</sub>Te, Ni<sub>3</sub>Ga, Lu<sub>3</sub>Be, Mn<sub>3</sub>Al, Ru<sub>3</sub>Al, Fe<sub>3</sub>As, Ta<sub>3</sub>Sn, Mn<sub>3</sub>Si, V<sub>3</sub>Se, U<sub>3</sub>Se, Co<sub>3</sub>Sn, Co<sub>3</sub>Be, Co<sub>3</sub>Ge, U<sub>3</sub>Si, Cr<sub>3</sub>Si, V<sub>3</sub>Bi, Tc<sub>3</sub>Al, La<sub>3</sub>Si, Rh<sub>3</sub>Sn, Cr<sub>3</sub>Al, U<sub>3</sub>As, Mn<sub>3</sub>Ga, Th<sub>3</sub>Si, Rh<sub>3</sub>Be, Ni<sub>3</sub>Be, Mn<sub>3</sub>Ge, Cr<sub>3</sub>Ge, Pd<sub>3</sub>Al, and Cr<sub>3</sub>Ga. In some embodiments, the homogenized alloy is substantially free of Co. In additional embodiments, the homogenized alloy is substantially free of Ni. In further embodiments, the homogenized alloy is substantially free of Fe. In still further embodiments, the homogenized alloy is substantially free of each of Co, Ni, and Fe.

The alloy material **513** may comprise at least one solid, substantially continuous alloy structure (e.g., an alloy foil, an alloy sheet, an alloy film, an alloy mesh) extending across (e.g., substantially across) one or more of the outermost boundaries (e.g., outermost vertical boundaries, outermost lateral boundaries) of at least the diamond-containing material **501**; or may comprise a volume (e.g., group, cluster) of relatively smaller, discrete alloy structures (e.g., discrete alloy particles) positioned relative to one another to form a larger structure exhibiting a desired geometric configuration about the outermost boundaries of at least the diamond-

containing material **501**, but substantially free of bonds directly coupling the relatively smaller, discrete alloy structures to one another. In some embodiments, the alloy material **513** comprises a single (e.g., only one) alloy structure (e.g., an alloy foil, an alloy sheet, an alloy film, an alloy shim, an alloy mesh) laterally extending substantially completely across opposing outermost vertical boundaries of the diamond-containing material **501** and the supporting substrate **504**. In additional embodiments, the alloy material **513** comprises a volume of discrete alloy particles that together laterally extend substantially completely across opposing outermost vertical boundaries of the diamond-containing material **501** and the supporting substrate **504**. In further embodiments, the alloy material **513** comprises multiple (e.g., more than one) solid, substantially continuous alloy structures (e.g., alloy foils, alloy sheets, alloy films, alloy shims, alloy meshes, combinations thereof) that together extend substantially completely across one or more (e.g., only one, multiple, all) outermost boundaries (e.g., outermost vertical boundaries, outermost lateral boundaries) of the diamond-containing material **501**. In yet further embodiments, the alloy material **513** comprises at least one volume of discrete alloy particles that together extend substantially completely across one or more (e.g., only one, multiple, all) outermost boundaries (e.g., outermost vertical boundaries, outermost lateral boundaries) of the diamond-containing material **501**. In yet still further embodiments, the alloy material **513** comprises at least one solid, substantially continuous alloy structure (e.g., an alloy foil, an alloy sheet, an alloy film, an alloy shim, an alloy mesh) and at least one volume of discrete alloy particles that together extend substantially completely across one or more (e.g., only one, multiple, all) outermost boundaries (e.g., outermost vertical boundaries, outermost lateral boundaries) of the diamond-containing material **501**.

Referring next to FIG. 5B, the diamond-containing material **501** (FIG. 5A), the supporting substrate **504**, and the alloy material **513** may be subjected to HTHP processing to form a cutting table **502**. The HTHP processing may include subjecting the diamond-containing material **501**, the supporting substrate **504**, and the alloy material **513** to elevated temperatures and elevated pressures in a directly pressurized and/or indirectly heated cell for a sufficient time to convert the discrete diamond particles of the diamond-containing material **501** into inter-bonded diamond particles. The temperatures (e.g., sintering temperature(s)) employed within the heated, pressurized cell may be greater than the solidus temperature (e.g., greater than the solidus temperature and less than or equal to the liquidus temperature, greater than or equal to the liquidus temperature, etc.) of the homogenized alloy of the alloy material **513**, and pressures within the heated, pressurized cell may be greater than or equal to about 2.0 GPa (e.g., greater than or equal to about 3.0 GPa, such as greater than or equal to about 4.0 GPa, greater than or equal to about 5.0 GPa, greater than or equal to about 6.0 GPa, greater than or equal to about 7.0 GPa, greater than or equal to about 8.0 GPa, or greater than or equal to about 9.0 GPa). The temperature(s) employed during the HTHP processing to form the cutting table **502** at least partially depend on the pressure(s) employed during the HTHP processing, and on the material composition of the homogenized alloy of the alloy material **513**. Employing pressure(s) above atmospheric pressure (1 atm) during the HTHP processing may affect (e.g., shift) metastability lines (e.g., phase boundaries) of the liquid (L)+diamond (D)+metal carbide (MC) phase field, which may influence (e.g., compel the increase of) the temperature(s) employed to form the cutting table **502**. In



addition, the material composition of the homogenized alloy of the alloy material **513** may affect (e.g., increase, decrease) the melting temperature(s) of the homogenized alloy, and may also affect (e.g., shift) the metastability lines of the L+D+MC+ $\kappa$ -carbide phase field, which may also impact (e.g., compel the increase of) the temperature(s) employed to form the cutting table **502**. The diamond-containing material **501**, the supporting substrate **504**, and the alloy material **513** may be held at selected temperatures and pressures within the heated, pressurized cell for a sufficient amount of time to facilitate the inter-bonding of the discrete diamond particles of the diamond-containing material **501**, such as a period of time between about 30 seconds and about 20 minutes.

During the HTHP processing, the homogenized alloy of the alloy material **513** melts and a portion thereof is swept (e.g., mass transported, diffused) into the diamond-containing material **501** (FIG. 5A). The homogenized alloy received by the diamond-containing material **501** catalyzes the formation of inter-granular bonds between the discrete diamond particles of the diamond-containing material **501** to form inter-bonded diamond particles, and also facilitates the formation of a thermally stable material (e.g., the thermally stable material **118** previously described with reference to FIG. 2) within interstitial spaces between the inter-bonded diamond particles of the cutting table **502**. When the homogenized alloy is in a liquid phase, the second element (e.g., one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, and B) of the homogenized alloy may reduce the reactivity of the first element (e.g., Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U) of the homogenized alloy with C, permitting the first element to catalyze the formation of inter-granular bonds between the discrete diamond particles of the diamond-containing material **501** and also promoting the formation of non-binary carbide precipitates (e.g., ternary  $\kappa$ -carbide precipitates, ternary non- $\kappa$ -carbide precipitates, quaternary  $\kappa$ -carbide precipitates, quaternary non- $\kappa$ -carbide precipitates) within the interstitial spaces between the inter-bonded diamond particles of the cutting table. Even if the first element comprises an element (e.g., Co, No, Ag, Cu, Au, Pt, Tc) that is not highly reactive with C to form a binary carbide, the second element may enhance the stability properties (e.g., thermal stability properties, mechanical stability properties) of the cutting table **502** by facilitating the formation of carbide precipitates (e.g.,  $\kappa$ -carbide precipitates, non- $\kappa$ -carbide precipitates) having formula (1) above. The thermally stable material of the cutting table **502** may render the cutting table **502** thermally stable without needing to leach the cutting table **502**. For example, the thermally stable material may not significantly promote carbon transformations (e.g., graphite-to-diamond or vice versa) as compared to conventional cutting tables including inter-bonded diamond particles substantially exposed to conventional catalyst materials (e.g., catalytic Co, catalytic Fe, catalytic Ni) within interstitial spaces between the inter-bonded diamond particles. Accordingly, the thermally stable material may render the cutting table **502** more thermally stable than conventional cutting tables.

Optionally, following formation, the cutting table **502** may be subjected to at least one solution treatment process to modify the material composition of the thermally stable material thereof. The solution treatment process may, for example, decompose carbide precipitates (e.g.,  $\kappa$ -carbide precipitates, non- $\kappa$ -carbide precipitates) of the thermally stable material into to one or more other precipitates, such as FCC L<sub>12</sub> phase precipitates. By way of non-limiting

example, if at least the alloy material **513** (FIG. 5A) effectuates the formation of a thermally stable material including  $\kappa$ -carbide precipitates in the cutting table **502**, the cutting table **502** may optionally be subjected to a solution treatment process that heats the thermally stable material at least to a decomposition temperature of the  $\kappa$ -carbide precipitates (e.g., a temperature greater than or equal to about 1000° C., such as from about 1000° C. to about 1500° C., or from about 1300° C. to about 1500° C.) at a pressure above the Berman-Simon line to decompose the  $\kappa$ -carbide precipitates and form FCC L<sub>12</sub> phase precipitates. If employed, the cutting table **502** may be subjected to a single (e.g., only one) solution treatment process employing a single temperature under pressure above the Berman-Simon line, or may be subjected to multiple (e.g., more than one) solution treatment processes employing different temperatures under pressure above the Berman-Simon line. Multiple solution treatment processes at different temperatures may, for example, facilitate the formation of precipitates (e.g., FCC L<sub>12</sub> phase precipitates) having different particle sizes than one another. Relatively larger precipitate sizes may enhance high-temperature properties (e.g., creep rupture properties) of the thermally stable material, and relatively smaller precipitate sizes may enhance room-temperature properties of the thermally stable material.

With returned reference to FIG. 1, while FIG. 1 depicts a particular configuration of the cutting element **100**, including particular configurations of the cutting table **102** and the supporting substrate **104** thereof, different configurations may be employed. One or more of the cutting table **102** and the supporting substrate **104** may, for example, exhibit a different shape (e.g., a dome shape, a conical shape, a frusto-conical shape, a rectangular column shape, a pyramidal shape, a frusto-pyramidal shape, a fin shape, a pillar shape, a stud shape, or an irregular shape) and/or a different size (e.g., a different diameter, a different height), and/or the interface **106** between the supporting substrate **104** and cutting table **102** may be non-planar (e.g., convex, concave, ridged, sinusoidal, angled, jagged, V-shaped, U-shaped, irregularly shaped, etc.). By way of non-limiting example, in accordance with additional embodiments of the disclosure, FIGS. 6 through 17 show simplified side elevation views of cutting elements exhibiting different configurations than that of the cutting element **100** shown in FIG. 1. Throughout FIGS. 6 through 17 and the description associated therewith, functionally similar features are referred to with similar reference numerals incremented by 100. To avoid repetition, not all features shown in FIGS. 6 through 17 are described in detail herein. Rather, unless described otherwise below, a feature designated by a reference numeral that is a 100 increment of the reference numeral of a feature previously described with respect to one or more of FIGS. 1 and 6 through 17 (whether the previously described feature is first described before the present paragraph, or is first described after the present paragraph) will be understood to be substantially similar to the previously described feature.

FIG. 6 illustrates a simplified side elevation view of a cutting element **600**, in accordance with another embodiment of the disclosure. The cutting element **600** includes a supporting substrate **604**, and a cutting table **602** attached to the supporting substrate **604** at an interface **606**. The cutting table **602** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table **102** previously described with reference to FIGS. 1 and 2. In addition, the supporting substrate **604** may have a material composition and a material distribution substantially similar to the



material composition and the material distribution of one or more of the supporting substrates **104**, **304**, **404**, **504** previously described with reference to FIGS. **1**, **3A**, **4A**, and **5A**. As shown in FIG. **6**, the cutting table **602** exhibits a generally conical shape, and includes a conical side surface **608** and an apex **601** (e.g., tip) that at least partially define a cutting face **610** of the cutting table **602**. The apex **601** comprises an end of the cutting table **602** opposing another end of the cutting table **602** secured to the supporting substrate **604** at the interface **606**. The conical side surface **608** extends upwardly and inwardly from or proximate the interface **606** toward the apex **601**. The apex **601** may be centered about a central longitudinal axis of the cutting element **600**, and may be at least partially (e.g., substantially) radiused (e.g., arcuate). The conical side surface **608** may be defined by at least one angle  $\theta$  between the conical side surface **608** and a phantom line **603** (shown in FIG. **6** with dashed lines) longitudinally extending from a lateral side surface of the supporting substrate **604**. The angle  $\theta$  may, for example, be within a range of from about five degrees ( $5^\circ$ ) to about eighty-five degrees ( $85^\circ$ ), such as from about fifteen degrees ( $15^\circ$ ) to about seventy-five degrees ( $75^\circ$ ), from about thirty degrees ( $30^\circ$ ) to about sixty degrees ( $60^\circ$ ), or from about forty-five degrees ( $45^\circ$ ) to about sixty degrees ( $60^\circ$ ). Ratios of a height of the cutting element **600** to outer diameters of the cutting element **600** may be within a range of from about 0.1 to about 48. The cutting element **600**, including the cutting table **602** and the supporting substrate **604** thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. **3A** through **5B** (e.g., a process substantially similar to that previously described with reference to FIGS. **3A** and **3B**; a process substantially similar to that previously described with reference to FIGS. **4A** and **4B**; a process substantially similar to that previously described with reference to FIGS. **5A** and **5B**).

FIG. **7** illustrates a simplified side elevation view of a cutting element **700**, in accordance with another embodiment of the disclosure. The cutting element **700** includes a supporting substrate **704**, and a cutting table **702** attached to the supporting substrate **704** at an interface **706**. The cutting table **702** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table **102** previously described with reference to FIGS. **1** and **2**. In addition, the supporting substrate **704** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates **104**, **304**, **404**, **504** previously described with reference to FIGS. **1**, **3A**, **4A**, and **5A**. As shown in FIG. **7**, the cutting table **702** exhibits a generally frusto-conical shape, and includes a conical side surface **708** and an apex **701** (e.g., tip) that at least partially define a cutting face **710** of the cutting table **702**. The apex **701** comprises an end of the cutting table **702** opposing another end of the cutting table **702** secured to the supporting substrate **704** at the interface **706**. The conical side surface **708** extends upwardly and inwardly from or proximate the interface **706** toward the apex **701**. The apex **701** may be centered about and may extend symmetrically outward diametrically from and perpendicular to a central longitudinal axis of the cutting element **700**. The apex **701** may exhibit a circular lateral shape or a non-circular lateral shape (e.g., a laterally elongated shape, such as a rectangular shape, a non-rectangular quadrilateral shape, an elliptical shape, etc.), and may be substantially flat (e.g., two-dimensional, planar, non-radiused, non-arcuate, non-curved). The

conical side surface **708** may be defined by at least one angle  $\theta$  between the conical side surface **708** and a phantom line **703** (shown in FIG. **7** with dashed lines) longitudinally extending from a lateral side surface of the supporting substrate **704**. The angle  $\theta$  may, for example, be within a range of from about  $5^\circ$  to about  $85^\circ$ , such as from about  $15^\circ$  to about  $75^\circ$ , from about  $30^\circ$  to about  $60^\circ$ , or from about  $45^\circ$  to about  $60^\circ$ . Interfaces (e.g., edges) between the conical side surface **708** and the apex **701** may be smooth and transitioned (e.g., chamfered and/or radiused), or may be sharp (e.g., non-chamfered and non-radiused). A ratio of an outer diameter of the cutting table **702** at the apex **701** relative to an outer diameter of the cutting table **702** at the interface **706** may be within a range of from about 0.001 to about 1. The cutting element **700**, including the cutting table **702** and the supporting substrate **704** thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. **3A** through **5B** (e.g., a process substantially similar to that previously described with reference to FIGS. **3A** and **3B**; a process substantially similar to that previously described with reference to FIGS. **4A** and **4B**; a process substantially similar to that previously described with reference to FIGS. **5A** and **5B**).

FIG. **8** illustrates a simplified side elevation view of a cutting element **800**, in accordance with another embodiment of the disclosure. The cutting element **800** includes a supporting substrate **804**, and a cutting table **802** attached to the supporting substrate **804** at an interface **806**. The cutting table **802** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table **102** previously described with reference to FIGS. **1** and **2**. In addition, the supporting substrate **804** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates **104**, **304**, **404**, **504** previously described with reference to FIGS. **1**, **3A**, **4A**, and **5A**. As shown in FIG. **8**, the cutting table **802** exhibits a generally frusto-conical shape, and includes a conical side surface **808** and an apex **801** (e.g., tip) that at least partially define a cutting face **810** of the cutting table **802**. The apex **801** comprises an end of the cutting table **802** opposing another end of the cutting table **802** secured to the supporting substrate **804** at the interface **806**. The conical side surface **808** extends upwardly and inwardly from or proximate the interface **806** toward the apex **801**. A center of the apex **801** may be laterally offset from a central longitudinal axis of the cutting element **800**. The apex **801** may exhibit a circular lateral shape or a non-circular lateral shape (e.g., a laterally elongated shape, such as a rectangular shape, a non-rectangular quadrilateral shape, an elliptical shape, etc.), and may be substantially flat (e.g., two-dimensional, planar, non-radiused, non-arcuate, non-curved). At least one region of the conical side surface **808** may be defined by at least one angle  $\theta$  between the conical side surface **808** and a phantom line **803** (shown in FIG. **8** with dashed lines) longitudinally extending from a lateral side surface of the supporting substrate **804**, and at least one other region of the conical side surface **808** may be defined by at least one additional angle  $\alpha$  between the conical side surface **808** and the phantom line **803**. The angle  $\theta$  may be greater than the additional angle  $\alpha$ . Each of the angle  $\theta$  and the additional angle  $\alpha$  may individually be within a range of from about  $5^\circ$  to about  $85^\circ$ . Interfaces (e.g., edges) between the conical side surface **808** and the apex **801** may be smooth and transitioned (e.g., chamfered and/or radiused), or may be



sharp (e.g., non-chamfered and non-radiused). A ratio of an outer diameter of the cutting table **802** at the apex **801** relative to an outer diameter of the cutting table **802** at the interface **806** may be within a range of from about 0.001 to about 1. The cutting element **800**, including the cutting table **802** and the supporting substrate **804** thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. **3A** through **5B** (e.g., a process substantially similar to that previously described with reference to FIGS. **3A** and **3B**; a process substantially similar to that previously described with reference to FIGS. **4A** and **4B**; a process substantially similar to that previously described with reference to FIGS. **5A** and **5B**).

FIG. **9** illustrates a simplified side elevation view of a cutting element **900**, in accordance with another embodiment of the disclosure. The cutting element **900** includes a supporting substrate **904**, and a cutting table **902** attached to the supporting substrate **904** at an interface **906**. The cutting table **902** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table **102** previously described with reference to FIGS. **1** and **2**. In addition, the supporting substrate **904** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates **104**, **304**, **404**, **504** previously described with reference to FIGS. **1**, **3A**, **4A**, and **5A**. As shown in FIG. **9**, the cutting table **902** exhibits a chisel shape, and includes opposing conical side surfaces **908**, opposing flat side surfaces **905**, and an apex **901** (e.g., tip) that at least partially define a cutting face **910** of the cutting table **902**. The apex **901** comprises an end of the cutting table **902** opposing another end of the cutting table **902** secured to the supporting substrate **904** at the interface **906**. The opposing conical side surfaces **908** extend upwardly and inwardly from or proximate the interface **906** toward the apex **901**. The opposing flat side surfaces **905** intervene between the opposing conical side surfaces **908**, and also extend upwardly and inwardly from or proximate the interface **906** toward the apex **901**. The apex **901** may be centered about and may extend symmetrically outward diametrically from and perpendicular to a central longitudinal axis of the cutting element **900**. The apex **901** may exhibit a circular lateral shape or a non-circular lateral shape (e.g., a laterally elongated shape, such as a rectangular shape, a non-rectangular quadrilateral shape, an elliptical shape, etc.), and may be either arcuate (e.g., non-planar, radiused, curved) or substantially flat (e.g., two-dimensional, planar, non-radiused, non-arcuate, non-curved). The opposing conical side surfaces **908** may be defined by at least one angle  $\theta$  between each of the opposing conical side surfaces **908** and a phantom line **903** (shown in FIG. **9** with dashed lines) longitudinally extending from a lateral side surface of the supporting substrate **904**. The angle  $\theta$  may, for example, be within a range of from about  $5^\circ$  to about  $85^\circ$ , such as from about  $15^\circ$  to about  $75^\circ$ , from about  $30^\circ$  to about  $60^\circ$ , or from about  $45^\circ$  to about  $60^\circ$ . The opposing flat side surfaces **905** may individually be defined by at least one other angle between the flat side surface **905** and the phantom line **903**, wherein the at least one other angle is different than (e.g., less than or greater than) the angle  $\theta$  between each of the opposing conical side surfaces **908** and the phantom line **903**. Interfaces between the opposing conical side surfaces **908**, the opposing flat side surfaces **905**, and the apex **901** may be smooth and transitioned (e.g., chamfered and/or radiused), or may be sharp (e.g., non-

chamfered and non-radiused). In some embodiments, a maximum height of the cutting element **900** is less than or equal to about 48 mm. The cutting element **900**, including the cutting table **902** and the supporting substrate **904** thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. **3A** through **5B** (e.g., a process substantially similar to that previously described with reference to FIGS. **3A** and **3B**; a process substantially similar to that previously described with reference to FIGS. **4A** and **4B**; a process substantially similar to that previously described with reference to FIGS. **5A** and **5B**).

FIG. **10** illustrates a simplified side elevation view of a cutting element **1000**, in accordance with another embodiment of the disclosure. The cutting element **1000** includes a supporting substrate **1004**, and a cutting table **1002** attached to the supporting substrate **1004** at an interface **1006**. The cutting table **1002** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table **102** previously described with reference to FIGS. **1** and **2**. In addition, the supporting substrate **1004** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates **104**, **304**, **404**, **504** previously described with reference to FIGS. **1**, **3A**, **4A**, and **5A**. As shown in FIG. **10**, the cutting table **1002** exhibits a chisel shape, and includes opposing conical side surfaces **1008**, opposing flat side surfaces **1005**, and an apex **1001** (e.g., tip) that at least partially define a cutting face **1010** of the cutting table **1002**. The apex **1001** comprises an end of the cutting table **1002** opposing another end of the cutting table **1002** secured to the supporting substrate **1004** at the interface **1006**. The opposing conical side surfaces **1008** extend upwardly and inwardly from or proximate the interface **1006** toward the apex **1001**. The opposing flat side surfaces **1005** intervene between the opposing conical side surfaces **1008**, and also extend upwardly and inwardly from or proximate the interface **1006** toward the apex **1001**. A center of the apex **1001** may be laterally offset from a central longitudinal axis of the cutting element **1000**. The apex **1001** may exhibit a circular lateral shape or a non-circular lateral shape (e.g., a laterally elongated shape, such as a rectangular shape, a non-rectangular quadrilateral shape, an elliptical shape, etc.), and may be either arcuate (e.g., non-planar, radiused, curved) or substantially flat (e.g., two-dimensional, planar, non-radiused, non-arcuate, non-curved). One of the opposing conical side surfaces **1008** may be defined by at least one angle  $\theta$  between the conical side surface **1008** and a phantom line **1003** (shown in FIG. **10** with dashed lines) longitudinally extending from a lateral side surface of the supporting substrate **1004**, and another of the opposing conical side surfaces **1008** may be defined by another angle less than the angle  $\theta$ . The angle  $\theta$  may be within a range of from about  $5^\circ$  to about  $85^\circ$ , such as from about  $15^\circ$  to about  $75^\circ$ , from about  $30^\circ$  to about  $60^\circ$ , or from about  $45^\circ$  to about  $60^\circ$ . The opposing flat side surfaces **1005** may individually be defined by at least one additional angle between the flat side surface **1005** and the phantom line **1003**, wherein the at least one additional angle is different than (e.g., less than or greater than) the angle  $\theta$ . Interfaces between the opposing conical side surfaces **1008**, the opposing flat side surfaces **1005**, and the apex **1001** may be smooth and transitioned (e.g., chamfered and/or radiused), or may be sharp (e.g., non-chamfered and non-radiused). The cutting element **1000**, including the cutting table **1002** and the supporting substrate **1004** thereof, may be formed using one or more



processes substantially similar to those previously described with reference to FIGS. 3A through 5B (e.g., a process substantially similar to that previously described with reference to FIGS. 3A and 3B; a process substantially similar to that previously described with reference to FIGS. 4A and 4B; a process substantially similar to that previously described with reference to FIGS. 5A and 5B).

FIG. 11 illustrates a simplified side elevation view of a cutting element 1100, in accordance with another embodiment of the disclosure. The cutting element 1100 includes a supporting substrate 1104, and a cutting table 1102 attached to the supporting substrate 1104 at an interface 1106. The cutting table 1102 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table 102 previously described with reference to FIGS. 1 and 2. In addition, the supporting substrate 1104 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates 104, 304, 404, 504 previously described with reference to FIGS. 1, 3A, 4A, and 5A. As shown in FIG. 11, the cutting table 1102 exhibits a chisel shape, and includes opposing conical side surfaces 1108, opposing flat side surfaces 1105, and an apex 1101 (e.g., tip) that at least partially define a cutting face 1110 of the cutting table 1102. The configuration of the cutting table 1102 is similar to the configuration of the cutting table 1002 (FIG. 10) except that the apex 1101 of the cutting table 1102 may extend non-perpendicular (e.g., non-orthogonal) to a central longitudinal axis of the cutting element 1100. For example, the apex 1101 of the cutting table 1102 may exhibit a negative slope or a positive slope. The cutting element 1100, including the cutting table 1102 and the supporting substrate 1104 thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. 3A through 5B (e.g., a process substantially similar to that previously described with reference to FIGS. 3A and 3B; a process substantially similar to that previously described with reference to FIGS. 4A and 4B; a process substantially similar to that previously described with reference to FIGS. 5A and 5B).

FIG. 12 illustrates a simplified side elevation view of a cutting element 1200, in accordance with another embodiment of the disclosure. The cutting element 1200 includes a supporting substrate 1204, and a cutting table 1202 attached to the supporting substrate 1204 at an interface 1206. The cutting table 1202 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table 102 previously described with reference to FIGS. 1 and 2. In addition, the supporting substrate 1204 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates 104, 304, 404, 504 previously described with reference to FIGS. 1, 3A, 4A, and 5A. As shown in FIG. 12, the cutting table 1202 exhibits a generally conical shape, and includes a semi-conical side surface 1208 and an apex 1201 (e.g., tip) that at least partially define a cutting face 1210 of the cutting table 1202. The apex 1201 comprises an end of the cutting table 1202 opposing another end of the cutting table 1202 secured to the supporting substrate 1204 at the interface 1206. The apex 1201 may be sharp (e.g., non-radiused), and may be centered about a central longitudinal axis of the cutting element 1200. For example, the apex 1201 may be a single (e.g., only one) point most distal from the interface 1206 between the supporting substrate 1204 and a cutting table 1202, or may

be a single line most distal from the interface 1206 between the supporting substrate 1204 and a cutting table 1202. The semi-conical side surface 1208 may include a first portion adjacent the supporting substrate 1204 and extending substantially parallel to a phantom line 1203 (shown in FIG. 12 with dashed lines) longitudinally extending from a lateral side surface of the supporting substrate 1204, and a second portion between the first portion and the apex 1201 and extending at an angle  $\theta$  relative to the phantom line 1203. The angle  $\theta$  may, for example, be within a range of from about  $5^\circ$  to about  $85^\circ$ , such as from about  $15^\circ$  to about  $75^\circ$ , from about  $30^\circ$  to about  $60^\circ$ , or from about  $45^\circ$  to about  $60^\circ$ . The cutting element 1200, including the cutting table 1202 and the supporting substrate 1204 thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. 3A through 5B (e.g., a process substantially similar to that previously described with reference to FIGS. 3A and 3B; a process substantially similar to that previously described with reference to FIGS. 4A and 4B; a process substantially similar to that previously described with reference to FIGS. 5A and 5B).

FIG. 13 illustrates a simplified side elevation view of a cutting element 1300, in accordance with another embodiment of the disclosure. The cutting element 1300 includes a supporting substrate 1304, and a cutting table 1302 attached to the supporting substrate 1304 at an interface 1306. The cutting table 1302 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table 102 previously described with reference to FIGS. 1 and 2. In addition, the supporting substrate 1304 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates 104, 304, 404, 504 previously described with reference to FIGS. 1, 3A, 4A, and 5A. As shown in FIG. 13, the cutting table 1302 exhibits a non-cylindrical shape, and includes a semi-conical side surface 1308 and an apex 1301 (e.g., tip) that at least partially define a cutting face 1310 of the cutting table 1302. The apex 1301 comprises an end of the cutting table 1302 opposing another end of the cutting table 1302 secured to the supporting substrate 1304 at the interface 1306. The apex 1301 may be sharp (e.g., non-radiused), and may be centered about a central longitudinal axis of the cutting element 1300. For example, the apex 1301 may be a single (e.g., only one) point most distal from the interface 1306 between the supporting substrate 1304 and a cutting table 1302, or may be a single line most distal from the interface 1306 between the supporting substrate 1304 and a cutting table 1302. The semi-conical side surface 1308 may include a first portion adjacent the supporting substrate 1304 and extending substantially parallel to a phantom line 1303 (shown in FIG. 13 with dashed lines) longitudinally extending from a lateral side surface of the supporting substrate 1304, a second portion adjacent the first portion and extending at an angle  $\gamma$  relative to the phantom line 1303, and a third portion between the second portion and the apex 1301 and extending at an angle  $\theta$  relative to the phantom line 1303. The angle  $\theta$  between the third portion of the semi-conical side surface 1308 and the phantom line 1303 may be greater than the angle  $\gamma$  between the second portion of the semi-conical side surface 1308 and the phantom line 1303. Each of the angle  $\gamma$  between the second portion of the semi-conical side surface 1308 and the phantom line 1303 and angle  $\theta$  between the third portion of the semi-conical side surface 1308 and the phantom line 1303 may individually be within



a range of from about 5° to about 85°. The cutting element **1300**, including the cutting table **1302** and the supporting substrate **1304** thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. **3A** through **5B** (e.g., a process substantially similar to that previously described with reference to FIGS. **3A** and **3B**; a process substantially similar to that previously described with reference to FIGS. **4A** and **4B**; a process substantially similar to that previously described with reference to FIGS. **5A** and **5B**).

FIG. **14** illustrates a simplified side elevation view of a cutting element **1400**, in accordance with another embodiment of the disclosure. The cutting element **1400** includes a supporting substrate **1404**, and a cutting table **1402** attached to the supporting substrate **1404** at an interface **1406**. The cutting table **1402** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table **102** previously described with reference to FIGS. **1** and **2**. In addition, the supporting substrate **1404** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates **104**, **304**, **404**, **504** previously described with reference to FIGS. **1**, **3A**, **4A**, and **5A**. As shown in FIG. **14**, the cutting table **1402** exhibits a non-cylindrical shape, and includes a semi-conical side surface **1408** and an apex **1401** (e.g., tip) that at least partially define a cutting face **1410** of the cutting table **1402**. The apex **1401** comprises an end of the cutting table **1402** opposing another end of the cutting table **1402** secured to the supporting substrate **1404** at the interface **1406**. The apex **1401** may be radiused (e.g., arcuate, curved), and may be centered about a central longitudinal axis of the cutting element **1400**. The semi-conical side surface **1408** may include a first portion adjacent the supporting substrate **1404** and extending substantially parallel to a phantom line **1403** (shown in FIG. **14** with dashed lines) longitudinally extending from a lateral side surface of the supporting substrate **1404**, and a second portion between the first portion and the apex **1401** and extending at an angle  $\theta$  relative to the phantom line **1403**. The angle  $\theta$  may, for example, be within a range of from about 5° to about 85°, such as from about 15° to about 75°, from about 30° to about 60°, or from about 45° to about 60°. The cutting element **1400**, including the cutting table **1402** and the supporting substrate **1404** thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. **3A** through **5B** (e.g., a process substantially similar to that previously described with reference to FIGS. **3A** and **3B**; a process substantially similar to that previously described with reference to FIGS. **4A** and **4B**; a process substantially similar to that previously described with reference to FIGS. **5A** and **5B**).

FIG. **15** illustrates a simplified side elevation view of a cutting element **1500**, in accordance with another embodiment of the disclosure. The cutting element **1500** includes a supporting substrate **1504**, and a cutting table **1502** attached to the supporting substrate **1504** at an interface **1506**. The cutting table **1502** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table **102** previously described with reference to FIGS. **1** and **2**. In addition, the supporting substrate **1504** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates **104**, **304**, **404**, **504** previously described with reference to FIGS. **1**, **3A**, **4A**, and

**5A**. As shown in FIG. **15**, the cutting table **1502** exhibits a generally hemispherical shape, and includes a semi-hemispherical side surface **1508** and an apex **1501** (e.g., tip) that at least partially define a cutting face **1510** of the cutting table **1502**. The apex **1501** comprises an end of the cutting table **1502** opposing another end of the cutting table **1502** secured to the supporting substrate **1504** at the interface **1506**. The apex **1501** may be radiused (e.g., arcuate, curved), and may be centered about a central longitudinal axis of the cutting element **1500**. The semi-hemispherical side surface **1508** may include a first portion adjacent the supporting substrate **1504** and extending substantially parallel to a lateral side surface of the supporting substrate **1504**, and a second portion extending in an arcuate (e.g., curved) path between the first portion and the apex **1501**. The cutting element **1500**, including the cutting table **1502** and the supporting substrate **1504** thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. **3A** through **5B** (e.g., a process substantially similar to that previously described with reference to FIGS. **3A** and **3B**; a process substantially similar to that previously described with reference to FIGS. **4A** and **4B**; a process substantially similar to that previously described with reference to FIGS. **5A** and **5B**).

FIG. **16** illustrates a simplified side elevation view of a cutting element **1600**, in accordance with another embodiment of the disclosure. The cutting element **1600** includes a supporting substrate **1604**, and a cutting table **1602** attached to the supporting substrate **1604** at an interface **1606**. The cutting table **1602** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table **102** previously described with reference to FIGS. **1** and **2**. In addition, the supporting substrate **1604** may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates **104**, **304**, **404**, **504** previously described with reference to FIGS. **1**, **3A**, **4A**, and **5A**. As shown in FIG. **16**, the cutting table **1602** exhibits a semi-hemispherical shape, and includes a semi-hemispherical side surface **1608**, a flat side surface **1607**, and an apex **1601** (e.g., tip) that at least partially define a cutting face **1610** of the cutting table **1602**. The apex **1601** comprises an end of the cutting table **1602** opposing another end of the cutting table **1602** secured to the supporting substrate **1604** at the interface **1606**. The semi-hemispherical side surface **1608** extends upwardly and inwardly from or proximate the interface **1606** toward the apex **1601**. The flat side surface **1607** opposes the semi-hemispherical side surface **1608**, and also extends upwardly and inwardly from or proximate the interface **1606** toward the apex **1601**. The apex **1601** may be centered a longitudinal axis of the cutting element **1600**. The semi-hemispherical side surface **1608** may include a first portion adjacent the supporting substrate **1604** and extending substantially parallel to a lateral side surface of the supporting substrate **1604**, and a second portion extending in an arcuate (e.g., curved) path between the first portion and the apex **1601**. The flat side surface **1607** may be substantially planar, and may be angled relative to a lateral side surface of the supporting substrate **1604**. Interfaces between the semi-hemispherical side surface **1608**, the flat side surface **1607**, and the apex **1601** may be smooth and transitioned (e.g., chamfered and/or radiused), or may be sharp (e.g., non-chamfered and non-radiused). The cutting element **1600**, including the cutting table **1602** and the supporting substrate **1604** thereof, may be formed using one or more processes substantially similar to those previously



described with reference to FIGS. 3A through 5B (e.g., a process substantially similar to that previously described with reference to FIGS. 3A and 3B; a process substantially similar to that previously described with reference to FIGS. 4A and 4B; a process substantially similar to that previously described with reference to FIGS. 5A and 5B).

FIG. 17 illustrates a simplified side elevation view of a cutting element 1700, in accordance with another embodiment of the disclosure. The cutting element 1700 includes a supporting substrate 1704, and a cutting table 1702 attached to the supporting substrate 1704 at an interface 1706. The cutting table 1702 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table 102 previously described with reference to FIGS. 1 and 2. In addition, the supporting substrate 1704 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates 104, 304, 404, 504 previously described with reference to FIGS. 1, 3A, 4A, and 5A. As shown in FIG. 17, the cutting table 1702 exhibits a semi-hemispherical shape, and includes a semi-hemispherical side surface 1708, a flat side surface 1707, and an apex 1701 (e.g., tip) that at least partially define a cutting face 1710 of the cutting table 1702. The configuration of the cutting table 1702 is similar to the configuration of the cutting table 1602 (FIG. 16) except that the apex 1701 of the cutting table 1702 is laterally offset from a central longitudinal axis of the cutting element 1700. Laterally offsetting the apex 1701 from the central longitudinal axis of the cutting element 1700 may extend the dimensions of the semi-hemispherical side surface 1708 relative to those of the semi-conical side surface 1408 (FIG. 14) of the cutting element 1400 (FIG. 14), and may reduce the dimensions and angle of the flat side surface 1707 relative to those of the flat side surface 1607 (FIG. 16) of the cutting element 1600 (FIG. 16). The cutting element 1700, including the cutting table 1702 and the supporting substrate 1704 thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. 3A through 5B (e.g., a process substantially similar to that previously described with reference to FIGS. 3A and 3B; a process substantially similar to that previously described with reference to FIGS. 4A and 4B; a process substantially similar to that previously described with reference to FIGS. 5A and 5B).

The methods of the disclosure may also be employed to form structures other than cutting elements. Namely, the methods of the disclosure may be used whenever it is desired to form a structure or device including a table of hard material, such as diamond table (e.g., PDC table). The methods of disclosure may, for example, be employed to form various other structures associated with (e.g., employed in) downhole operations, such as bearing structures (e.g., bearing pads, bearing discs, bearing blocks, bearing sleeves), wear structures (e.g., wear pads, wear discs, wear block), block structures, die structures (e.g., tool die structures, wire die structures), and/or other structures. By way of non-limiting example, FIGS. 18 and 19 show additional structures (e.g., a bearing structure, a die structure) that may be formed in accordance with embodiments of the disclosure.

FIG. 18 illustrates a perspective view of a bearing structure 1800, in accordance with another embodiment of the disclosure. The bearing structure 1800 includes a supporting substrate 1804, and a hard material table 1802 (e.g., PDC table) attached to the supporting substrate 1804 at an inter-

face 1806. The hard material table 1802 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table 102 previously described with reference to FIGS. 1 and 2. In addition, the supporting substrate 1804 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of one or more of the supporting substrates 104, 304, 404, 504 previously described with reference to FIGS. 1, 3A, 4A, and 5A. The bearing structure 1800 may exhibit any desired peripheral geometric configuration (e.g., peripheral shape and peripheral size) suitable for a predetermined use of the bearing structure 1800. By way of non-limiting example, as shown in FIG. 18, the bearing structure 1800 may exhibit an elongate 3D shape, such as an ellipsoidal cylinder shape. In additional embodiments, the bearing structure 1800 may exhibit a different peripheral shape (e.g., a rectangular cylinder shape; circular cylinder shape; a conical shape; a frusto-conical shape; truncated versions thereof; or an irregular shape, such as a complex shape complementary to a recess or socket in an earth-boring tool to receive and hold the bearing structure 1800). In addition, the interface 1806 between the supporting substrate 1804 and the hard material table 1802 may be substantially planar, or may be non-planar (e.g., curved, angled, jagged, sinusoidal, V-shaped, U-shaped, irregularly shaped, combinations thereof, etc.). The bearing structure 1800, including the hard material table 1802 and the supporting substrate 1804 thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. 3A through 5B (e.g., a process substantially similar to that previously described with reference to FIGS. 3A and 3B; a process substantially similar to that previously described with reference to FIGS. 4A and 4B; a process substantially similar to that previously described with reference to FIGS. 5A and 5B).

FIG. 19 illustrates a perspective view of die structure 1900, in accordance with another embodiment of the disclosure. The die structure 1900 includes a hard material table 1902 (e.g., PDC table), wherein the hard material table 1902 may have a material composition and a material distribution substantially similar to the material composition and the material distribution of the cutting table 102 previously described with reference to FIGS. 1 and 2. The die structure 1900 may exhibit any desired peripheral geometric configuration (e.g., peripheral shape and peripheral size) suitable for a predetermined use of the die structure 1900, such as a peripheral geometric configuration complementary to formation of another structure (e.g., an earth-boring tool structure, a wire structure) having a desired and predetermined peripheral geometric configuration. By way of non-limiting example, as shown in FIG. 19, the die structure 1900 may exhibit an at least partially (e.g., substantially) hollow elongate 3D shape, such as a tubular shape. In additional embodiments, the die structure 1900 may exhibit a different peripheral shape, such as an at least partially hollow form of a conical, cubic, cuboidal, cylindrical, semi-cylindrical, spherical, semi-spherical, triangular prismatic, or irregular shape. The die structure 1900, including the hard material table 1902 thereof, may be formed using one or more processes substantially similar to those previously described with reference to FIGS. 3A through 5B (e.g., a process substantially similar to that previously described with reference to FIGS. 3A and 3B; a process substantially similar to that previously described with reference to FIGS. 4A and 4B; a process substantially similar to that previously described with reference to FIGS. 5A and 5B).



Embodiments of cutting elements (e.g., the cutting elements **100**, **600**, **700**, **800**, **900**, **1000**, **1100**, **1200**, **1300**, **1400**, **1500**, **1600**, **1700** illustrated in FIGS. **1** and **6** through **17**) described herein may be secured to an earth-boring tool and used to remove subterranean formation material in accordance with additional embodiments of the disclosure. The earth-boring tool may, for example, be a rotary drill bit, a percussion bit, a coring bit, an eccentric bit, a reamer tool, a milling tool, etc. As a non-limiting example, FIG. **20** illustrates a fixed-cutter type earth-boring rotary drill bit **2000** that includes cutting elements **2002**. One or more of the cutting elements **2002** may be substantially similar to one or more of the cutting elements **100**, **600**, **700**, **800**, **900**, **1000**, **1100**, **1200**, **1300**, **1400**, **1500**, **1600**, **1700** previously described herein with respect to FIGS. **1** and **6** through **17**, and may be formed in accordance to the processes previously described herein with reference to FIGS. **3A** through **5B** (e.g., a process substantially similar to that previously described with reference to FIGS. **3A** and **3B**; a process substantially similar to that previously described with reference to FIGS. **4A** and **4B**; a process substantially similar to that previously described with reference to FIGS. **5A** and **5B**). The rotary drill bit **2000** includes a bit body **2004**, and the cutting elements **2002** are attached to the bit body **2004**. The cutting elements **2002** may, for example, be brazed, welded, or otherwise secured, within pockets formed in an outer surface of the bit body **2004**. Optionally, the rotary drill bit **2000** may also include one or more other structures

(e.g., bearing structures, wear structures, block structures) formed according to embodiments of the disclosure, such as the bearing structure **1800** previously described herein with respect to FIG. **18**.

The following example serves to explain some embodiments of the present disclosure in more detail. The example is not to be construed as being exhaustive or exclusive as to the scope of the disclosure.

#### Example

The stabilities (e.g., thermal stabilities, and mechanical stabilities) of different  $\kappa$ -carbide precipitates were evaluated using Vienna Ab-initio computer simulation package (VASP) methodologies. The analysis evaluated enthalpy of formation and eigenvalue from Young's modulus calculation for the different  $\kappa$ -carbide precipitates. Table 1 below summarizes the results of the analysis. As shown in Table 1, the  $\kappa$ -carbide precipitates each had an enthalpy of formation that was less than zero (indicating that the  $\kappa$ -carbide precipitate is thermally stable). In addition, each of the  $\kappa$ -carbide precipitates listed in Table 1 had an eigenvalue from a Young's modulus calculation that was positive (indicating that the  $\kappa$ -carbide precipitate is mechanically stable). The results indicate that each of the  $\kappa$ -carbide precipitates listed in Table 1 are stable and suitable for inclusion in a thermally stable material of a hard material structure (e.g., cutting table) for use in an earth-boring tool.

TABLE 1

$\kappa$ -carbide precipitate	Enthalpy of Formation (KJ/mol)	$\kappa$ -carbide precipitate	Enthalpy of Formation (KJ/mol)	$\kappa$ -carbide precipitate	Enthalpy of Formation (KJ/mol)
Sm <sub>3</sub> SnC	-704.822	Sm <sub>3</sub> BiC	-698.476	Sm <sub>3</sub> TeC	-680.23
Sm <sub>3</sub> PC	-628.793	Sm <sub>3</sub> SiC	-605.694	Sm <sub>3</sub> GaC	-456.928
Sc <sub>3</sub> SnC	-401.508	Sc <sub>3</sub> GeC	-392.05	Sc <sub>3</sub> SbC	-378.622
Sc <sub>3</sub> AsC	-374.565	Sm <sub>3</sub> BeC	-368.085	Sc <sub>3</sub> PC	-361.205
Sc <sub>3</sub> SiC	-354.422	Y <sub>3</sub> SnC	-350.531	Sc <sub>3</sub> BiC	-344.436
Tm <sub>3</sub> SnC	-342.149	Er <sub>3</sub> SnC	-339.945	Sc <sub>3</sub> TeC	-339.294
Y <sub>3</sub> SbC	-336.165	Sc <sub>3</sub> SeC	-336.02	Ho <sub>3</sub> SnC	-336
Sc <sub>3</sub> GaC	-333.574	Dy <sub>3</sub> SnC	-330.185	Y <sub>3</sub> BiC	-325.21
Tb <sub>3</sub> SnC	-322.851	Tm <sub>3</sub> SbC	-321.617	Er <sub>3</sub> SbC	-321.554
Lu <sub>3</sub> SbC	-320.949	Lu <sub>3</sub> GeC	-317.071	Ti <sub>3</sub> GaC	-314.641
Ti <sub>3</sub> GeC	-314.539	Gd <sub>3</sub> SnC	-312.478	Tb <sub>3</sub> SbC	-312.211
Y <sub>3</sub> GeC	-311.336	Er <sub>3</sub> BiC	-310.831	Ho <sub>3</sub> BiC	-310.214
Tm <sub>3</sub> BiC	-309.923	Lu <sub>3</sub> AsC	-309.917	Tm <sub>3</sub> GeC	-308.447
Dy <sub>3</sub> BiC	-307.974	Lu <sub>3</sub> BiC	-306.895	Tm <sub>3</sub> AsC	-305.001
Tb <sub>3</sub> BiC	-304.29	Ti <sub>3</sub> SnC	-303.132	Er <sub>3</sub> AsC	-302.427
Ti <sub>3</sub> SiC	-301.968	Y <sub>3</sub> TeC	-299.938	Gd <sub>3</sub> BiC	-297.664
Ce <sub>3</sub> TeC	-296.429	Ti <sub>3</sub> AlC	-295.679	Zr <sub>3</sub> SnC	-293.917
Dy <sub>3</sub> AsC	-292.429	La <sub>3</sub> BiC	-292.319	Sc <sub>3</sub> AlC	-291.925
Yb <sub>3</sub> SeC	-286.034	Tb <sub>3</sub> AsC	-284.901	Lu <sub>3</sub> PC	-282.484
Yb <sub>3</sub> TeC	-282.293	Lu <sub>3</sub> SnC	-281.097	Eu <sub>3</sub> SeC	-278.937
Er <sub>3</sub> TeC	-278.876	Ti <sub>3</sub> SbC	-276.999	Lu <sub>3</sub> SiC	-276.354
Tm <sub>3</sub> TeC	-276.141	Tm <sub>3</sub> PC	-275.024	Gd <sub>3</sub> TeC	-274.579
Gd <sub>3</sub> AsC	-274.349	Zr <sub>3</sub> SbC	-274.346	Lu <sub>3</sub> GaC	-271.369
Er <sub>3</sub> PC	-271.368	Sm <sub>3</sub> BC	-270.449	Lu <sub>3</sub> TeC	-270.02
Ho <sub>3</sub> PC	-266.29	Tm <sub>3</sub> SiC	-265.632	Er <sub>3</sub> SiC	-260.226
Dy <sub>3</sub> PC	-259.237	Tm <sub>3</sub> GaC	-256.175	Ce <sub>3</sub> AsC	-254.551
Y <sub>3</sub> GaC	-253.35	Ho <sub>3</sub> SiC	-253.253	Tb <sub>3</sub> PC	-250.6
Er <sub>3</sub> GaC	-248.557	Dy <sub>3</sub> SiC	-244.364	Eu <sub>3</sub> BiC	-242.797
Hf <sub>3</sub> GaC	-240.6	Ho <sub>3</sub> GaC	-239.225	Gd <sub>3</sub> PC	-238.928
Gd <sub>3</sub> SeC	-237.084	Lu <sub>3</sub> AlC	-236.831	Ce <sub>3</sub> SnC	-235.456
Tb <sub>3</sub> SiC	-233.924	Hf <sub>3</sub> SnC	-231.962	Dy <sub>3</sub> GaC	-228.5
Tm <sub>3</sub> AlC	-222.698	Gd <sub>3</sub> SiC	-220.401	Ti <sub>3</sub> BiC	-216.955
Tb <sub>3</sub> GaC	-216.845	Er <sub>3</sub> AlC	-215.553	Yb <sub>3</sub> BiC	-215.171
Yb <sub>3</sub> SbC	-215.169	La <sub>3</sub> PC	-215.099	Eu <sub>3</sub> AsC	-214.244
Fe <sub>3</sub> AlC	-210.127	Ho <sub>3</sub> AlC	-206.657	Gd <sub>3</sub> GaC	-202.834
Yb <sub>3</sub> AsC	-202.589	Th <sub>3</sub> BiC	-198.184	Ac <sub>3</sub> SbC	-194.323
Th <sub>3</sub> SnC	-193.111	Tb <sub>3</sub> AlC	-185.118	Eu <sub>3</sub> PC	-184.188
Fe <sub>3</sub> SiC	-183.358	Ti <sub>3</sub> BeC	-182.722	Yb <sub>3</sub> PC	-177.404
Gd <sub>3</sub> AlC	-171.312	Hf <sub>3</sub> PC	-169.998	V <sub>3</sub> SiC	-167.077
Ce <sub>3</sub> SiC	-160.936	V <sub>3</sub> GeC	-156.93	Fe <sub>3</sub> GaC	-154.834



TABLE 1-continued

$\kappa$ -carbide precipitate	Enthalpy of Formation (KJ/mol)	$\kappa$ -carbide precipitate	Enthalpy of Formation (KJ/mol)	$\kappa$ -carbide precipitate	Enthalpy of Formation (KJ/mol)
Rh <sub>3</sub> AlC	-154.2	Th <sub>3</sub> GeC	-147.293	V <sub>3</sub> AlC	-145.097
Fe <sub>3</sub> GeC	-142.829	V <sub>3</sub> GaC	-141.158	Th <sub>3</sub> PC	-135.138
V <sub>3</sub> PC	-132.001	V <sub>3</sub> SnC	-122.954	Fe <sub>3</sub> SnC	-121.707
Zr <sub>3</sub> BeC	-120.908	Hf <sub>3</sub> BeC	-118.593	Nb <sub>3</sub> GaC	-116.249
Sc <sub>3</sub> BeC	-115.788	Th <sub>3</sub> AlC	-115.145	V <sub>3</sub> SbC	-112.187
Ce <sub>3</sub> AlC	-109.525	V <sub>3</sub> AsC	-108.401	Ni <sub>3</sub> AlC	-107.311
Ti <sub>3</sub> BC	-90.6332	Rh <sub>3</sub> GaC	-87.8091	Fe <sub>3</sub> BeC	-81.5766
Fe <sub>3</sub> SbC	-79.5255	Sc <sub>3</sub> BC	-75.0164	U <sub>3</sub> PC	-74.7
Fe <sub>3</sub> PC	-71.9518	Hf <sub>3</sub> BiC	-65.1081	V <sub>3</sub> BeC	-60.2572
V <sub>3</sub> TeC	-57.678	Ni <sub>3</sub> GaC	-55.3182	Lu <sub>3</sub> BeC	-53.9309
Mn <sub>3</sub> AlC	-53.5059	Ru <sub>3</sub> AlC	-52.9992	Fe <sub>3</sub> AsC	-51.9214
Ta <sub>3</sub> SnC	-48.3087	Mn <sub>3</sub> SiC	-47.6618	V <sub>3</sub> SeC	-44.3932
U <sub>3</sub> SeC	-43.7951	U <sub>3</sub> SiC	-34.204	Cr <sub>3</sub> SiC	-31.172
V <sub>3</sub> BiC	-26.412	Tc <sub>3</sub> AlC	-23.8878	La <sub>3</sub> SiC	-21.94
Rh <sub>3</sub> SnC	-20.2771	Cr <sub>3</sub> AlC	-19.8249	U <sub>3</sub> AsC	-14.1404
Mn <sub>3</sub> GaC	-13.0819	Th <sub>3</sub> SiC	-11.3861	Rh <sub>3</sub> BeC	-10.6868
Ni <sub>3</sub> BeC	-8.44939	Mn <sub>3</sub> GeC	-7.60212	Cr <sub>3</sub> GeC	-4.23139
Pd <sub>3</sub> AlC	-2.3424	Cr <sub>3</sub> GaC	-0.66372	Co <sub>3</sub> AlC	-157.648
Co <sub>3</sub> GaC	-100.221	Co <sub>3</sub> SiC	-66.0251	Co <sub>3</sub> SnC	-42.3607
Co <sub>3</sub> BeC	-41.6805	Co <sub>3</sub> GeC	-37.7468		

While the disclosure is susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, the disclosure is not limited to the particular forms disclosed. Rather, the disclosure is to cover all modifications, equivalents, and alternatives falling within the scope of the following appended claims and their legal equivalent. For example, elements and features disclosed in relation to one embodiment may be combined with elements and features disclosed in relation to other embodiments of the disclosure.

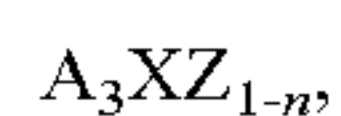
What is claimed is:

1. A cutting element, comprising:

a cutting table comprising:

inter-bonded diamond particles; and

a thermally stable material within interstitial spaces between the inter-bonded diamond particles, the thermally stable material comprising a ternary  $\kappa$ -carbide precipitate having the general chemical formula:



where A comprises only one of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, or U;

X comprises only one of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, or P;

Z comprises C; and

n is greater than or equal to 0 and less than or equal to 0.75; and

one or more of an FCC L1<sub>2</sub> phase precipitate, an FCC DO<sub>22</sub> phase precipitate, a D8<sub>5</sub> phase precipitate, a DO<sub>19</sub> phase precipitate, a BCC/B2 phase precipitate, and an FCC L1<sub>0</sub> phase precipitate.

2. The cutting element of claim 1, wherein the ternary  $\kappa$ -carbide precipitate is selected from Sm<sub>3</sub>SnC<sub>1-n</sub>, Sm<sub>3</sub>BiC<sub>1-n</sub>, Sm<sub>3</sub>TeC<sub>1-n</sub>, Sm<sub>3</sub>PC<sub>1-n</sub>, Sm<sub>3</sub>SiC<sub>1-n</sub>, Sm<sub>3</sub>GaC<sub>1-n</sub>, Sc<sub>3</sub>SnC<sub>1-n</sub>, Sc<sub>3</sub>GeC<sub>1-n</sub>, Sc<sub>3</sub>SbC<sub>1-n</sub>, Sc<sub>3</sub>AsC<sub>1-n</sub>, Sm<sub>3</sub>BeC<sub>1-n</sub>, Sc<sub>3</sub>PC<sub>1-n</sub>, Sc<sub>3</sub>SiC<sub>1-n</sub>, Y<sub>3</sub>SnC<sub>1-n</sub>, Sc<sub>3</sub>BiC<sub>1-n</sub>, Tm<sub>3</sub>SnC<sub>1-n</sub>, Er<sub>3</sub>SnC<sub>1-n</sub>, Sc<sub>3</sub>TeC<sub>1-n</sub>, Y<sub>3</sub>SbC<sub>1-n</sub>, Sc<sub>3</sub>SeC<sub>1-n</sub>, Ho<sub>3</sub>SnC<sub>1-n</sub>, Sc<sub>3</sub>GaC<sub>1-n</sub>, Dy<sub>3</sub>SnC<sub>1-n</sub>, Y<sub>3</sub>BiC<sub>1-n</sub>, Tb<sub>3</sub>SnC<sub>1-n</sub>, Tm<sub>3</sub>SbC<sub>1-n</sub>,

Er<sub>3</sub>SbC<sub>1-n</sub>, Lu<sub>3</sub>SbC<sub>1-n</sub>, Lu<sub>3</sub>GeC<sub>1-n</sub>, Ti<sub>3</sub>GaC<sub>1-n</sub>, Ti<sub>3</sub>GeC<sub>1-n</sub>, Gd<sub>3</sub>SnC<sub>1-n</sub>, Tb<sub>3</sub>SbC<sub>1-n</sub>, Y<sub>3</sub>GeC<sub>1-n</sub>, Er<sub>3</sub>BiC<sub>1-n</sub>, Ho<sub>3</sub>BiC<sub>1-n</sub>, Tm<sub>3</sub>BiC<sub>1-n</sub>, Lu<sub>3</sub>AsC<sub>1-n</sub>, Tm<sub>3</sub>GeC<sub>1-n</sub>, Dy<sub>3</sub>BiC<sub>1-n</sub>, Lu<sub>3</sub>BiC<sub>1-n</sub>, Tm<sub>3</sub>AsC<sub>1-n</sub>, Tb<sub>3</sub>BiC<sub>1-n</sub>, Ti<sub>3</sub>SnC<sub>1-n</sub>, Er<sub>3</sub>AsC<sub>1-n</sub>, Ti<sub>3</sub>SiC<sub>1-n</sub>, Y<sub>3</sub>TeC<sub>1-n</sub>, Gd<sub>3</sub>BiC<sub>1-n</sub>, Ce<sub>3</sub>TeC<sub>1-n</sub>, Ti<sub>3</sub>AlC<sub>1-n</sub>, Zr<sub>3</sub>SnC<sub>1-n</sub>, Dy<sub>3</sub>AsC<sub>1-n</sub>, La<sub>3</sub>BiC<sub>1-n</sub>, Sc<sub>3</sub>AlC<sub>1-n</sub>, Yb<sub>3</sub>SeC<sub>1-n</sub>, Tb<sub>3</sub>AsC<sub>1-n</sub>, Lu<sub>3</sub>PC<sub>1-n</sub>, Yb<sub>3</sub>TeC<sub>1-n</sub>, Lu<sub>3</sub>SnC<sub>1-n</sub>, Eu<sub>3</sub>SeC<sub>1-n</sub>, Er<sub>3</sub>TeC<sub>1-n</sub>, Ti<sub>3</sub>SbC<sub>1-n</sub>, Lu<sub>3</sub>SiC<sub>1-n</sub>, Tm<sub>3</sub>TeC<sub>1-n</sub>, Tm<sub>3</sub>PC<sub>1-n</sub>, Gd<sub>3</sub>TeC<sub>1-n</sub>, Gd<sub>3</sub>AsC<sub>1-n</sub>, Zr<sub>3</sub>SbC<sub>1-n</sub>, Lu<sub>3</sub>GaC<sub>1-n</sub>, Er<sub>3</sub>PC<sub>1-n</sub>, Sm<sub>3</sub>BC<sub>1-n</sub>, Lu<sub>3</sub>TeC<sub>1-n</sub>, Ho<sub>3</sub>PC<sub>1-n</sub>, Tm<sub>3</sub>SiC<sub>1-n</sub>, Er<sub>3</sub>SiC<sub>1-n</sub>, Dy<sub>3</sub>PC<sub>1-n</sub>, Tm<sub>3</sub>GaC<sub>1-n</sub>, Ce<sub>3</sub>AsC<sub>1-n</sub>, Y<sub>3</sub>GaC<sub>1-n</sub>, Ho<sub>3</sub>SiC<sub>1-n</sub>, Tb<sub>3</sub>PC<sub>1-n</sub>, Er<sub>3</sub>GaC<sub>1-n</sub>, Dy<sub>3</sub>SiC<sub>1-n</sub>, Eu<sub>3</sub>BiC<sub>1-n</sub>, Hf<sub>3</sub>GaC<sub>1-n</sub>, Ho<sub>3</sub>GaC<sub>1-n</sub>, Gd<sub>3</sub>PC<sub>1-n</sub>, Gd<sub>3</sub>SeC<sub>1-n</sub>, Lu<sub>3</sub>AlC<sub>1-n</sub>, Ce<sub>3</sub>SnC<sub>1-n</sub>, Tb<sub>3</sub>SiC<sub>1-n</sub>, Hf<sub>3</sub>SnC<sub>1-n</sub>, Dy<sub>3</sub>GaC<sub>1-n</sub>, Tm<sub>3</sub>AlC<sub>1-n</sub>, Gd<sub>3</sub>SiC<sub>1-n</sub>, Ti<sub>3</sub>BiC<sub>1-n</sub>, Tb<sub>3</sub>GaC<sub>1-n</sub>, Er<sub>3</sub>AlC<sub>1-n</sub>, Yb<sub>3</sub>BiC<sub>1-n</sub>, Yb<sub>3</sub>SbC<sub>1-n</sub>, La<sub>3</sub>PC<sub>1-n</sub>, Eu<sub>3</sub>AsC<sub>1-n</sub>, Fe<sub>3</sub>AlC<sub>1-n</sub>, Ho<sub>3</sub>AlC<sub>1-n</sub>, Gd<sub>3</sub>GaC<sub>1-n</sub>, Yb<sub>3</sub>AsC<sub>1-n</sub>, Th<sub>3</sub>BiC<sub>1-n</sub>, Ac<sub>3</sub>SbC<sub>1-n</sub>, Th<sub>3</sub>SnC<sub>1-n</sub>, Tb<sub>3</sub>AlC<sub>1-n</sub>, Eu<sub>3</sub>PC<sub>1-n</sub>, Fe<sub>3</sub>SiC<sub>1-n</sub>, Ti<sub>3</sub>BeC<sub>1-n</sub>, Yb<sub>3</sub>PC<sub>1-n</sub>, Gd<sub>3</sub>AlC<sub>1-n</sub>, Hf<sub>3</sub>PC<sub>1-n</sub>, V<sub>3</sub>SiC<sub>1-n</sub>, Ce<sub>3</sub>SiC<sub>1-n</sub>, V<sub>3</sub>GeC<sub>1-n</sub>, Fe<sub>3</sub>GaC<sub>1-n</sub>, Rh<sub>3</sub>AlC<sub>1-n</sub>, Th<sub>3</sub>GeC<sub>1-n</sub>, V<sub>3</sub>AlC<sub>1-n</sub>, Fe<sub>3</sub>GeC<sub>1-n</sub>, V<sub>3</sub>GaC<sub>1-n</sub>, Th<sub>3</sub>PC<sub>1-n</sub>, V<sub>3</sub>PC<sub>1-n</sub>, V<sub>3</sub>SnC<sub>1-n</sub>, Fe<sub>3</sub>SnC<sub>1-n</sub>, Zr<sub>3</sub>BeC<sub>1-n</sub>, Hf<sub>3</sub>BeC<sub>1-n</sub>, Nb<sub>3</sub>GaC<sub>1-n</sub>, Sc<sub>3</sub>BeC<sub>1-n</sub>, Th<sub>3</sub>AlC<sub>1-n</sub>, V<sub>3</sub>SbC<sub>1-n</sub>, Ce<sub>3</sub>AlC<sub>1-n</sub>, Co<sub>3</sub>AlC<sub>1-n</sub>, V<sub>3</sub>AsC<sub>1-n</sub>, Ni<sub>3</sub>AlC<sub>1-n</sub>, Co<sub>3</sub>GaC<sub>1-n</sub>, Ti<sub>3</sub>BC<sub>1-n</sub>, Rh<sub>3</sub>GaC<sub>1-n</sub>, Fe<sub>3</sub>BeC<sub>1-n</sub>, Fe<sub>3</sub>SbC<sub>1-n</sub>, Sc<sub>3</sub>BC<sub>1-n</sub>, U<sub>3</sub>PC<sub>1-n</sub>, Fe<sub>3</sub>PC<sub>1-n</sub>, Co<sub>3</sub>SiC<sub>1-n</sub>, Hf<sub>3</sub>BiC<sub>1-n</sub>, V<sub>3</sub>BeC<sub>1-n</sub>, V<sub>3</sub>TeC<sub>1-n</sub>, Ni<sub>3</sub>GaC<sub>1-n</sub>, Lu<sub>3</sub>BeC<sub>1-n</sub>, Mn<sub>3</sub>AlC<sub>1-n</sub>, Ru<sub>3</sub>AlC<sub>1-n</sub>, Fe<sub>3</sub>AsC<sub>1-n</sub>, Ta<sub>3</sub>SnC<sub>1-n</sub>, Mn<sub>3</sub>SiC<sub>1-n</sub>, V<sub>3</sub>SeC<sub>1-n</sub>, U<sub>3</sub>SeC<sub>1-n</sub>, Co<sub>3</sub>SnC<sub>1-n</sub>, Co<sub>3</sub>BeC<sub>1-n</sub>, Co<sub>3</sub>GeC<sub>1-n</sub>, U<sub>3</sub>SiC<sub>1-n</sub>, Cr<sub>3</sub>SiC<sub>1-n</sub>, V<sub>3</sub>BiC<sub>1-n</sub>, Tc<sub>3</sub>AlC<sub>1-n</sub>, La<sub>3</sub>SiC<sub>1-n</sub>, Rh<sub>3</sub>SnC<sub>1-n</sub>, Cr<sub>3</sub>AlC<sub>1-n</sub>, U<sub>3</sub>AsC<sub>1-n</sub>, Mn<sub>3</sub>GaC<sub>1-n</sub>, Th<sub>3</sub>SiC<sub>1-n</sub>, Rh<sub>3</sub>BeC<sub>1-n</sub>, Ni<sub>3</sub>BeC<sub>1-n</sub>, Mn<sub>3</sub>GeC<sub>1-n</sub>, Cr<sub>3</sub>GeC<sub>1-n</sub>, Pd<sub>3</sub>AlC<sub>1-n</sub>, and Cr<sub>3</sub>GaC<sub>1-n</sub>, wherein 0 ≤ n ≤ 0.75.

3. The cutting element of claim 1, wherein the ternary  $\kappa$ -carbide precipitate is substantially free of Co.

4. The cutting element of claim 1, wherein the cutting table exhibits one or more of radiused edges and chamfered edges.

5. The cutting element of claim 1, wherein X comprises one of Al, Ga, Sn, Be, Ge, or Si.

6. The cutting element of claim 1, wherein the thermally stable material substantially covers surfaces of the inter-bonded diamond particles of the cutting table.

7. The cutting element of claim 6, wherein any unreacted catalytic elements present within the cutting table are separated from the inter-bonded diamond particles by the thermally stable material.



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8. The cutting element of claim 1, wherein the thermally stable material is substantially free of binary carbide precipitates.

9. The cutting element of claim 1, further comprising a supporting substrate at an end of the cutting table, wherein the supporting substrate comprises:

a homogenized binder comprising C, W, one or more of Sc, Ti, V, Cr, Mn, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, and U, and one or more of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P; and

WC particles dispersed in the homogenized binder.

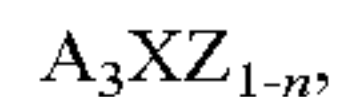
10. The cutting element of claim 9, wherein the supporting substrate is substantially free of catalytic Co.

11. A cutting element, comprising:

a cutting table comprising:

inter-bonded diamond particles; and

a thermally stable material within interstitial spaces between the inter-bonded diamond particles, the thermally stable material comprising a quaternary  $\kappa$ -carbide precipitate having the general chemical formula:



where A comprises only one of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Th, Pa, or U;

X comprises two of Al, Ga, Sn, Be, Bi, Te, Sb, Se, As, Ge, Si, B, and P; and

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Z comprises C; and

n is greater than or equal to 0 and less than or equal to 0.75.

12. The cutting element of claim 11, wherein X comprises two of Al, Ga, Sn, Be, Ge, and Si.

13. The cutting element of claim 11, wherein X comprises Al and one of Ga, Sn, Be, Ge, and Si.

14. The cutting element of claim 11, wherein:

A comprises one of Co, Ag, Cu, Au, Pt, and Tc; and

X is configured to enhance stability of the thermally stable material.

15. The cutting element of claim 11, wherein the thermally stable material is substantially free of a catalyst material without leaching.

16. The cutting element of claim 11, wherein the thermally stable material is substantially free of Co.

17. The cutting element of claim 11, wherein the thermally stable material comprises FCC  $L1_2$  phase precipitates.

18. The cutting element of claim 11, further comprising a supporting substrate at an end of the cutting table, the supporting substrate comprising:

a homogenized binder comprising a substantially homogeneous alloy; and

WC particles dispersed in the homogenized binder.

19. The cutting element of claim 18, wherein the homogenized binder is substantially free of each of Co, Ni, and Fe.

20. The cutting element of claim 18, wherein the homogenized binder has a melting temperature greater than or equal to about 750° C.

\* \* \* \* \*



UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 12,098,597 B2  
APPLICATION NO. : 17/804915  
DATED : September 24, 2024  
INVENTOR(S) : Wanjun Cao and Marc Bird

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 10,	Line 20,	change "other R phase" to --other $\beta$ phase--
Column 27,	Line 19,	change "Yb <sub>3</sub> As, Tb <sub>3</sub> Bi, Ac <sub>3</sub> Sb," to --Yb <sub>3</sub> As, Th <sub>3</sub> Bi, Ac <sub>3</sub> Sb,--
Column 38,	Line 7,	change "about 300 to" to --about 30° to--
Column 38,	Line 7,	change "from about 450" to --from about 45°--
Column 39,	Line 57,	change "about 150 to" to --about 15° to--
Column 39,	Line 58,	change "about 450 to" to --about 45° to--
Column 40,	Line 55,	change "about 150 to" to --about 15° to--
Column 40,	Line 56,	change "about 300 to" to --about 30° to--
Column 40,	Line 56,	change "about 450 to" to --about 45° to--
Column 42,	Line 12,	change "about 450 to" to --about 45° to--
Column 43,	Line 44,	change "450 to about 60°." to --45° to about 60°.--

Signed and Sealed this  
Twelfth Day of November, 2024  
*Katherine Kelly Vidal*

Katherine Kelly Vidal  
Director of the United States Patent and Trademark Office